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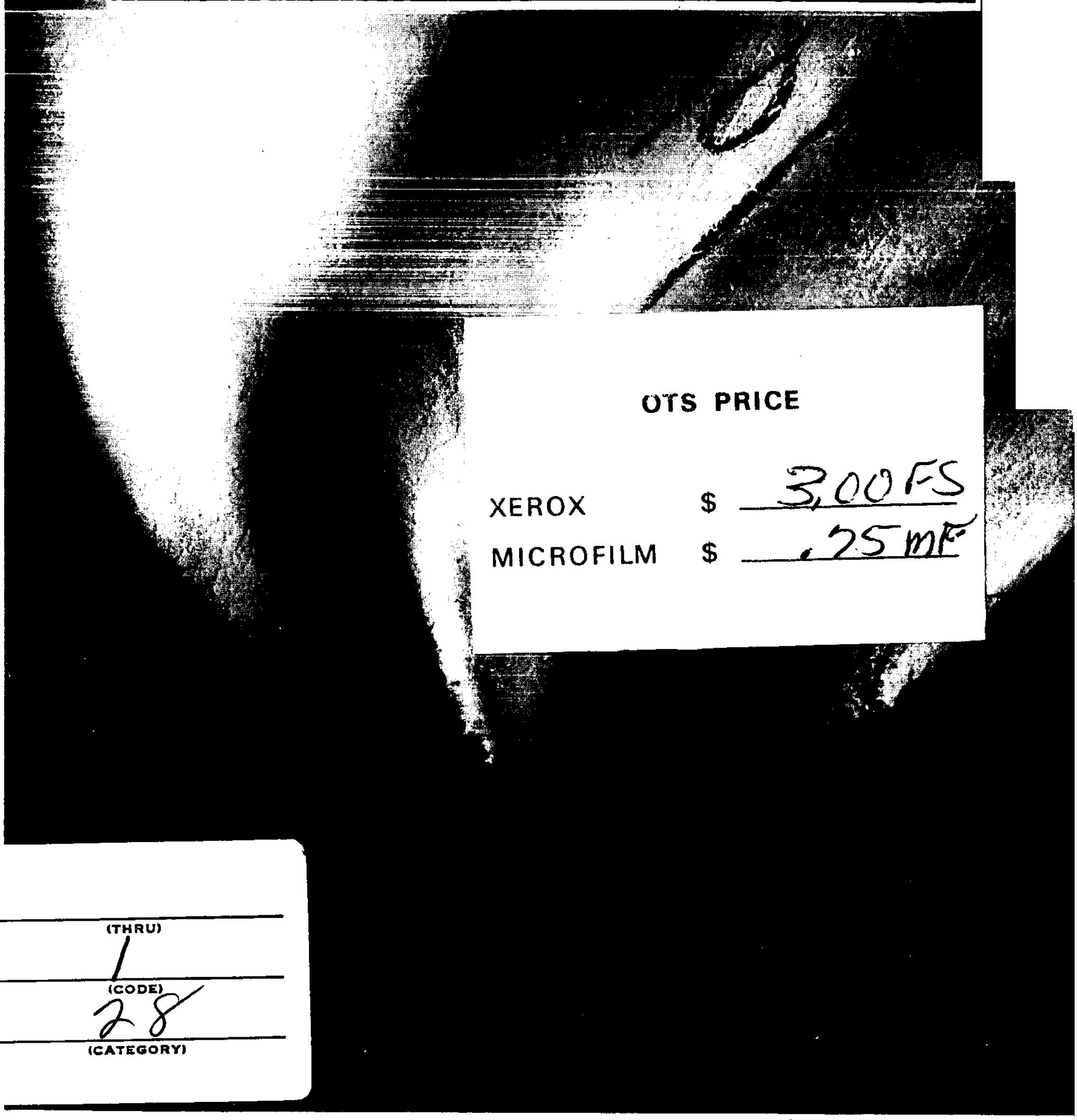

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AN INVESTIGATION OF SELECTED TYPES OF RADIOWAVE ABSORPTION EVENTS IN THE AURORAL ZONE

by

F. T. Berkey and R. Parthasarathy

SCIENTIFIC REPORT
May 1964

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Report approved by:

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ABSTRACT

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As a result of a study of cosmic radiowave absorption records for the period 1961-1963 from a network of Alaskan riometer stations located near the auroral zone maximum, three characteristic absorption events have been identified: (1) Type F events, characterized by a sudden increase in absorption (<5 min); (2) Type S events, characterized by a slow increase and slow recovery of absorption ($\lesssim$30 min), and which occur during quiet conditions, and; (3) Type P events, characterized by a more or less regular periodicity of absorption. The temporal and spatial aspects of these events were investigated and found to vary with geomagnetic latitude.

Magnetometer records and all-sky camera data were analyzed simultaneously with the riometer data, yielding several interesting relationships. Type F events were found to be related to the well known breakup phase of the aurora occurring near the midnight meridian and also to the sudden increase of the H-component of the magnetograms at the onset of a negative bay. Type S events are connected with the characteristically less violent breakup of auroral displays occurring near the dawn meridian and often with negative bay-type magnetic disturbances. Type P events were found to occur simultaneously with magnetic pulsations.

It is shown that Type F absorption events can be useful in identifying conjugate pairs. A small amount of observational

data indicates that Type S events may also be of limited use in conjugate investigations.

By means of multiple frequency data for the Type F and S events, it is also shown that the ionization extends very much below the altitude of the associated visual auroral displays.

Author

ACKNOWLEDGMENTS

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The high quality draftsmanship is due to the skill of Mr. Ken Bettisworth and the arduous task of typing the manuscript was ably handled by Mrs. Virginia Duncan.

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CHAPTER I

FEATURES OF HIGH-LATITUDE ABSORPTION

The measurement of cosmic-noise radio-wave absorption introduced by Shain (1951) and Mitra and Shain (1953) has provided a powerful tool for study of the upper atmosphere. Such a method is especially useful at high latitudes where serious VHF absorption is frequent. Little and Leinbach (1958, 1959) have adapted the radiometer developed by Machin, Ryle and Vonberg (1952) for use in measuring radio-wave absorption. A careful design should ensure that an output is only slightly dependent on system gain variations. The instrument, particularly the more recent versions by commercial manufacturers, has proven to be suitable for field operation and has been in use at various field sites in the polar regions since 1958.

At the auroral-zone latitudes four distinct categories of absorption phenomena are observed. During the sudden cosmic noise absorption (SCNA) events simultaneous with certain solar flares, the absorption increases suddenly and recovers to a normal level usually within an hour. These events are recorded only over the sunlit hemisphere and are thought to be caused by the hard x-ray emissions ($\geq$10 A) from certain solar flares.

Polar-cap absorption (PCA) phenomena are observed throughout the polar regions, polewards from about 60° geomagnetic latitude. The absorption increases slowly, reaching a maximum level many hours following the solar flare and often lasts for several days. Low energy solar protons are responsible for PCA absorption events, [Forbush (1946) and Bailey (1957)].

Sudden commencement absorption (SCA), associated with the sudden commencement of earth storms, resembles, on the record, an SCNA, but may be recorded simultaneously in both the day and night hemispheres. However, the absorption is apparently limited to stations near the auroral zone maximum, Brown et al. (1961).

Auroral absorption (AA) records are characterized by the irregular variation of the cosmic noise level. Rapid increases, as well as extended periods of absorption are common features of these records. These absorption events may be correlated with visual aurora and magnetic disturbances, [Little and Leinbach (1958)].

Of the four types of absorption discussed above, the nature and origin of the first three types has been established. However, due to the complex nature of auroral absorption events and their non-uniformity from station-to-station and from event-to-event, they are more difficult to analyze. Studies by Little and Leinbach (1958), Basler (1961), Holt, Landmark and Lied (1962) and Hartz (1963) have defined the zone of maximum absorption and determined the daily variation for various longitudes. The above investigations have used absorption magnitudes irrespective of the intrinsic features of the absorption events. Therefore, a study was initiated to examine the absorption records for identifiable features, and to investigate their spatial and temporal aspects. Three distinct events have emerged as a result of this study and their variation in space, time, and magnitude form the basis of this investigation. These events may be described as follows:

The first category of events, called Type F in this study, are characterized by a flash-like increase of absorption. All events studied reached their maxima within five minutes and many of them, within a minute. During the absorption events of duration greater than five minutes, Type F events often formed part of the absorption increase and were considered as separate events. See Fig. 1 for an example of the Type F absorption event.

A second category is the smoothly varying absorption (Fig. 8) events which reach maximum absorption within twenty to thirty minutes of their time of onset. These events have been termed absorption bays by Ziauddin (1961) and are called Type S here. The criterion for selecting these events was a lack of auroral absorption activity for at least four hours prior to the onset of the event, and at least two hours following (Fig. 8).

The third category is the pulsating absorption events, Type P, of a 'sinusoidal' nature. It was required that at least four cycles of the sinuosoid appear.

It may be noted that the above identifications have received cognizance by the earlier workers in the field; here they shall be subjected to detailed investigation.

Little and Leinbach (1958) examined the broad and narrow antenna beam absorption values for a number of "singular" events. These singular events were described as "occasions during which the absorption increased markedly from the predisturbance level and decreased to approximately the original level within 15 minutes or less." They found these singular events to be connected with visual aurora. They concluded from their

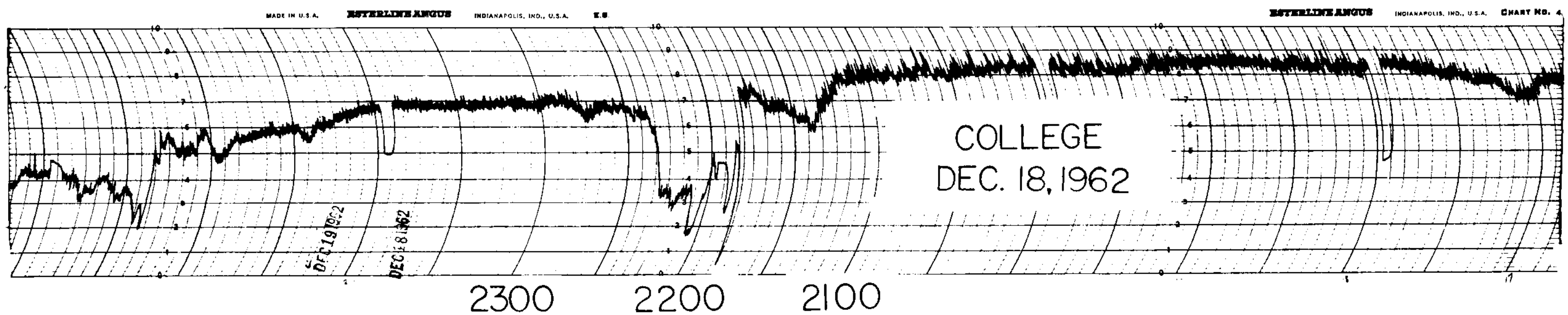

Fig. 1 The Type F event occurring at 2148 LT is the most prominent feature of this absorption record. Several other Type F events occur following this event.

investigation that the absorbing region had dimensions greater than the pattern of the broad-beam antenna (200 kilometers by 90 kilometers) and that absorbing regions on the order of 5-50 kilometers were not present.

Gustafsson (1962, 1963) has studied the aurorally associated events characterized by a rapid increase in absorption (Type F). He has related these 'breakup' events to disturbances of the magnetic field and changes in auroral luminosity. However, physical inferences concerning the D-region based on single frequency absorption data cannot be considered as unambiguous.

Ansari (1963) made a detailed study of cosmic noise absorption and its relation to luminous aurora. Pre-breakup and post-breakup events were investigated utilizing a narrow-beam antenna array switchable to the north and south of the zenith. He found that the ratio of absorption to the luminosity before breakup changed dramatically in favor of relatively more absorption.

Ziauddin (1960, 1961) showed the relation between a pulsating absorption event at Saskatoon (Saskatchewan) and coincident variations in H-component of the earth's field. He found that the pulsations were sometimes in phase and at other times 180° out of phase. Ziauddin (1961) has also investigated the relation between absorption bays and magnetic bays, finding among other results, a time lag between the two events.

Parthasarathy and Hessler (1964) have also examined some samples of co-variation of absorption pulsations and earth current records. They also found that the intensity of 5577 A emission had the same periodicity.

CHAPTER II

OBSERVATIONAL RESULTS

2.1 Introduction

The data used in this work was gathered at Fort Yukon, College, Healy, and Kotzebue, Alaska. Three months of data from Macquarie Island in the South Pacific, whose conjugate region lies near Kotzebue, was also used. As depicted in Fig. 2, Fort Yukon, College, and Healy lie nearly on the same geomagnetic meridian, while Kotzebue lies to the west of this meridian. (See Table 1 for the geographic and geomagnetic coordinates of these stations.) Fig. 2 also represents the projections on the earth of the intersections of the antenna patterns at the half-power points with a horizontal plane at a height of 100 km. Thus they represent the approximate area from which cosmic noise was received at each station.

The data used are continuous from 1961 for College and Fort Yukon, and from 1962 for Kotzebue. The Healy data were available from June 1962 through February 1963. Macquarie Island data for January, February and March 1962 were used.

The cosmic noise receivers operated at 27.6 megacycles for all stations except Kotzebue which received at 30.0 mc/s. Vertically directed, three element Yagi antennas, with half-power beam widths of about 60 by 120 degrees in the E and H planes were used.

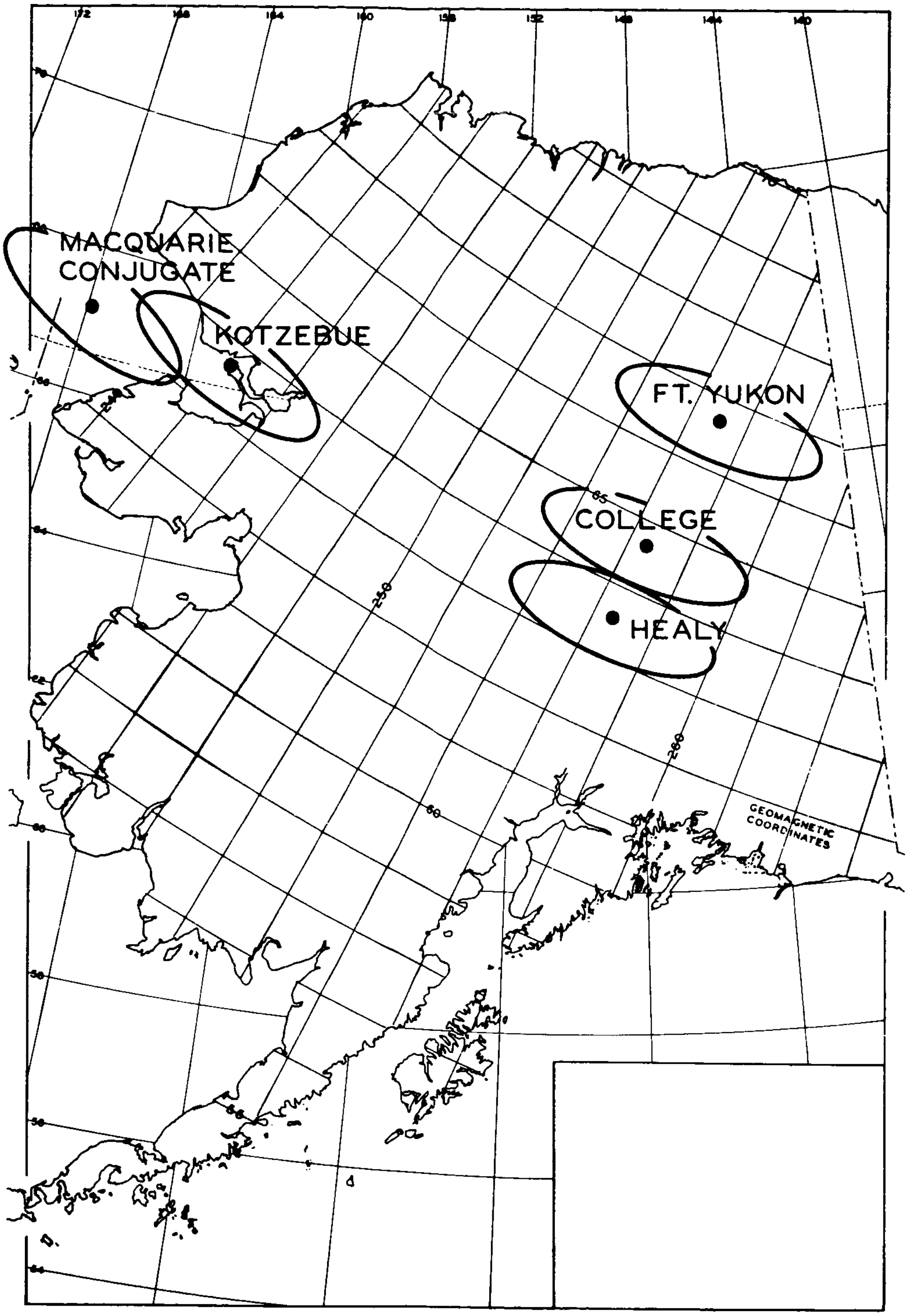

Fig. 2 The location of the Alaskan stations and the point conjugate to Macquarie Island (as calculated by C. G. Little). Recent studies by Wescott (1964) indicate that the Macquarie conjugate point may lie closer to Kotzebue than indicated here. The ellipses represent the projections on the earth of the intersections of the antenna patterns at the half-power points with a horizontal plane at a height of 100 km. Thus they represent the approximate area from which the cosmic noise was received at each station.

TABLE 1

	GEOGRAPHIC		GEOMAGNETIC	
	Latitude	Longitude	Latitude	Longitude
FORT YUKON	66° 34'N	145° 18'W	66.69°N	257.05°E
COLLEGE	64° 52'N	147° 49'W	64.65°N	256.56°E
HEALY	63° 51'N	148° 58'W	63.56°N	256.40°E
KOTZEBUE	66° 52'N	162° 30'W	63.65°N	242.04°E
MACQUARIE	54° 30'S	158° 57'E	61.1°S	243.1°E
MACQUARIE-	67.12°N	167.75°W[1]		
CONJUGATE	67.35°N	164.17°W[2]		

1 as calculated by Jensen and Whitaker

2 as calculated by Jensen and Cain

[see Wescott (1964)]

2.2 Type F Absorption Events

For each Type F event, two measurements of absorption have been made. The first value, designated F_t, represents the usual measurement of absorption, that is, from the quiet-day curve to the point of maximum absorption. The other value, F_r, is the magnitude of the sudden increase in absorption measured from the pre-disturbance level. This latter value has been used most extensively in this study since it was thought to be an equally meaningful parameter, and free from the uncertainties in the quiet-day curve.

The seasonal variation of more than 1200 Type F events was investigated and is shown in Fig. 3. No consistent pattern emerges but it does seem as though a maximum occurs around the autumn equinox. At Fort Yukon the minimum tends to occur before the spring equinox. College displays the same pattern as Fort Yukon for 1962 but has no pattern for 1961 or 1963. Kotzebue shows a maximum during the autumn equinox but gaps in the data make the pattern uncertain. There was insufficient data at Healy to form a seasonal variation.

Daily variations for each station are shown in Fig. 4. At Fort Yukon and College, the absorption events are centered around local midnight. The maximum occurs just before midnight at Fort Yukon and just afterward at College. Healy shows no definite pattern at all. For local time at Kotzebue the time scale must be shifted one hour to the right. The Kotzebue maximum then occurs just before local midnight. Plotting all stations in 150 west meridian time, the maximum occurs one hour

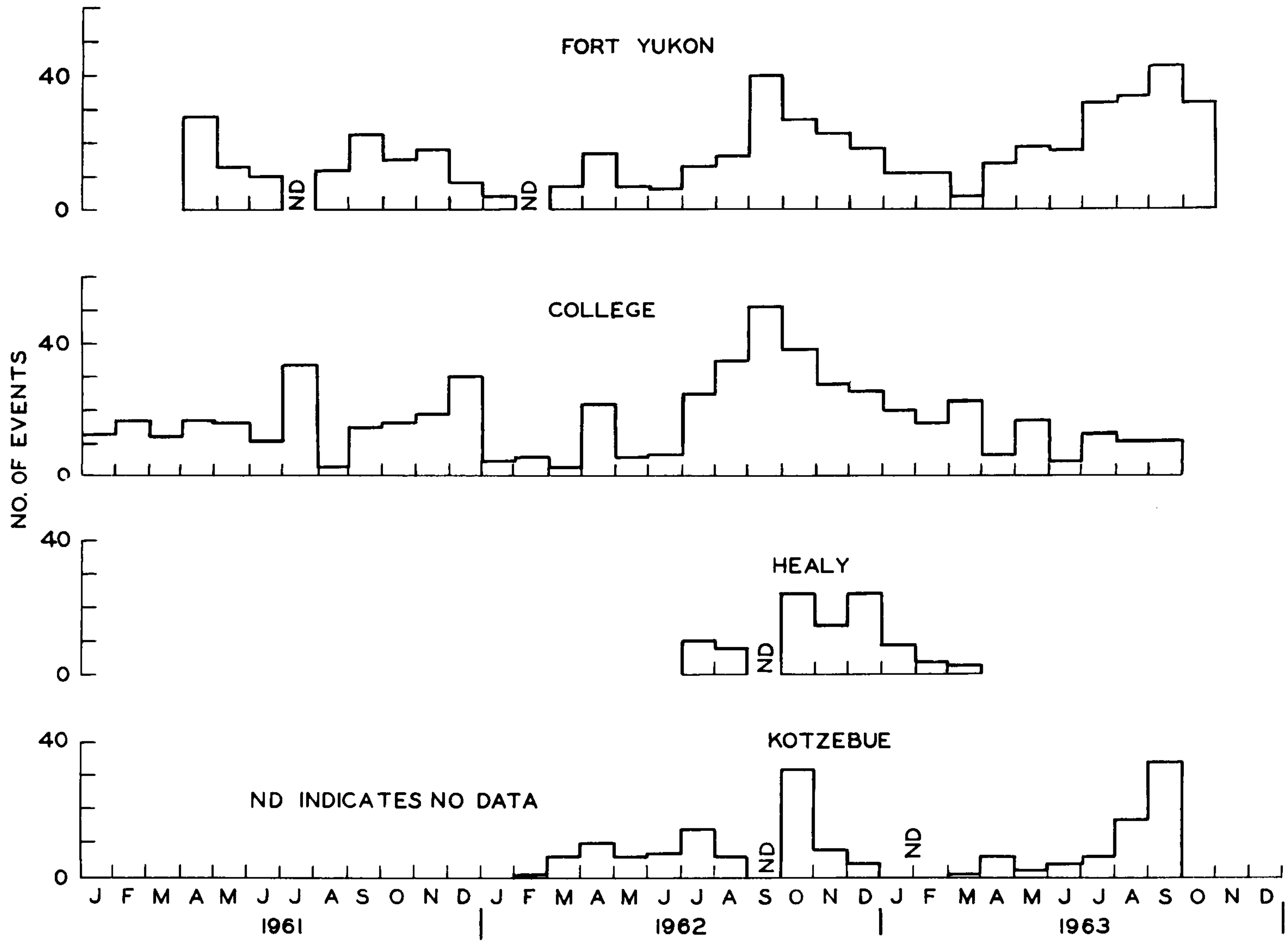

Fig. 3 The seasonal variation of Type F absorption events.

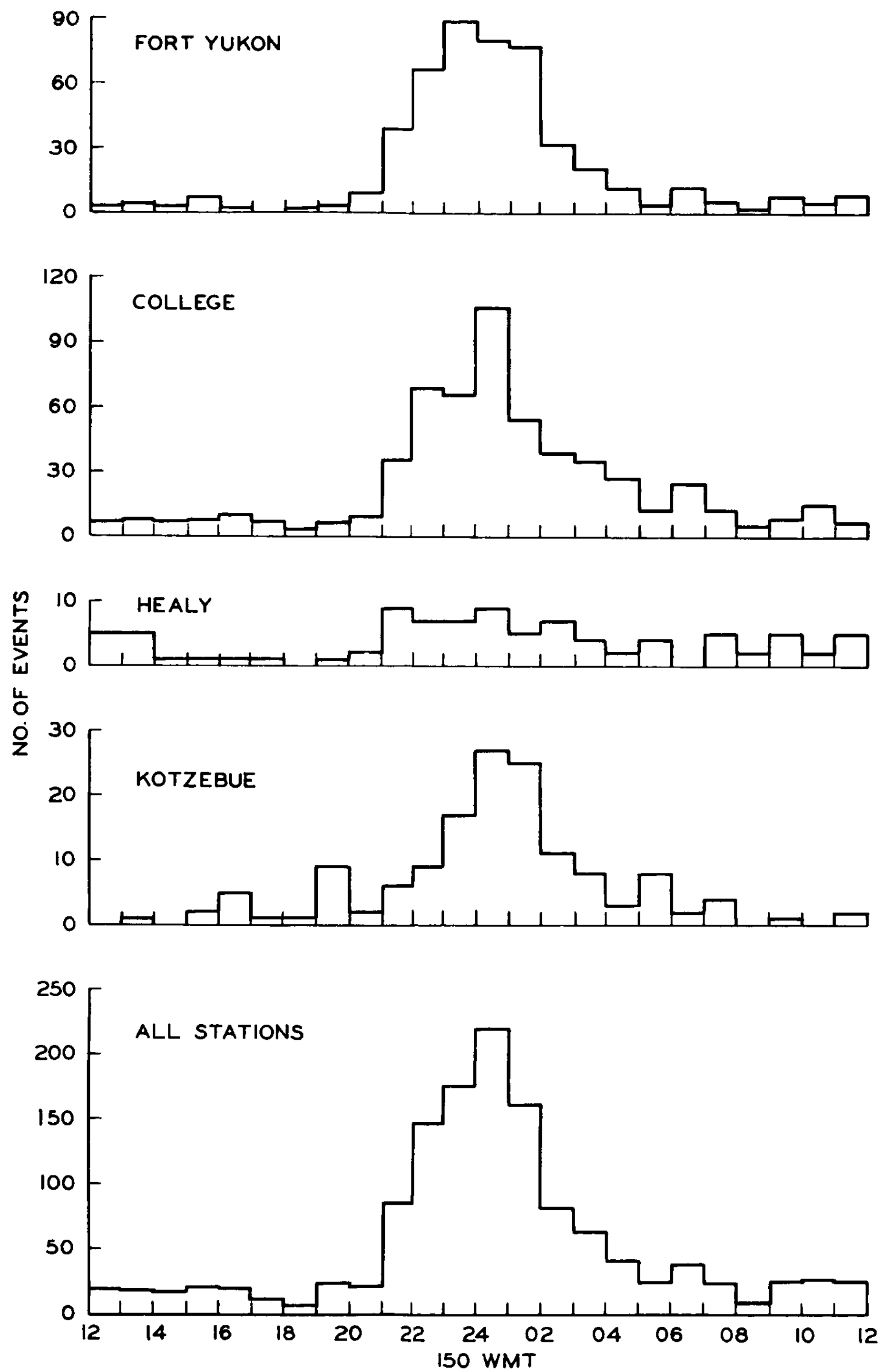

Fig. 4 The daily variation of Type F absorption events.

after midnight and a definite minima appears near 1900 hours. Alternately, the maximum may be interpreted as occurring at magnetic midnight. It may be of interest to note here that the favored time for the occurrence of negative magnetic bays is known to be around the magnetic midnight, for all high latitude stations [See, e.g. Zelwer (1963)].

It may be of interest to compare the daily variation found here with the percentage of hourly occurrence of visual aurora centered over College found by Davis (1962). The connection between the Type F events and the instantaneous features of visual aurora will be investigated in Chapter IV.

The amplitude distribution of Type F_f is shown in Fig. 5. The maximum number of events at Fort Yukon and College occurred between an amplitude of 1.0 and 1.5 decibels while the maximum at Kotzebue and Healy is between 1.5 and 2.0 db. It should be noted that the Kotzebue data has not been corrected for the higher frequency of operation; the data should be multiplied by 1.18 to obtain the corresponding 27.6 mc/s data.

The amplitude distribution measured from the quiet-day curve is represented in Fig. 6. Again, when the absorption values at Kotzebue are increased by 1.18, the station is found to show a maximum of occurrence at a higher absorption level than College or Fort Yukon.

In a crude sense, absorption may be thought of as proportional to the square root of the particle flux. The most favored magnitudes can then be thought of as representing a certain most favored particle flux, which is a higher value for Kotzebue.

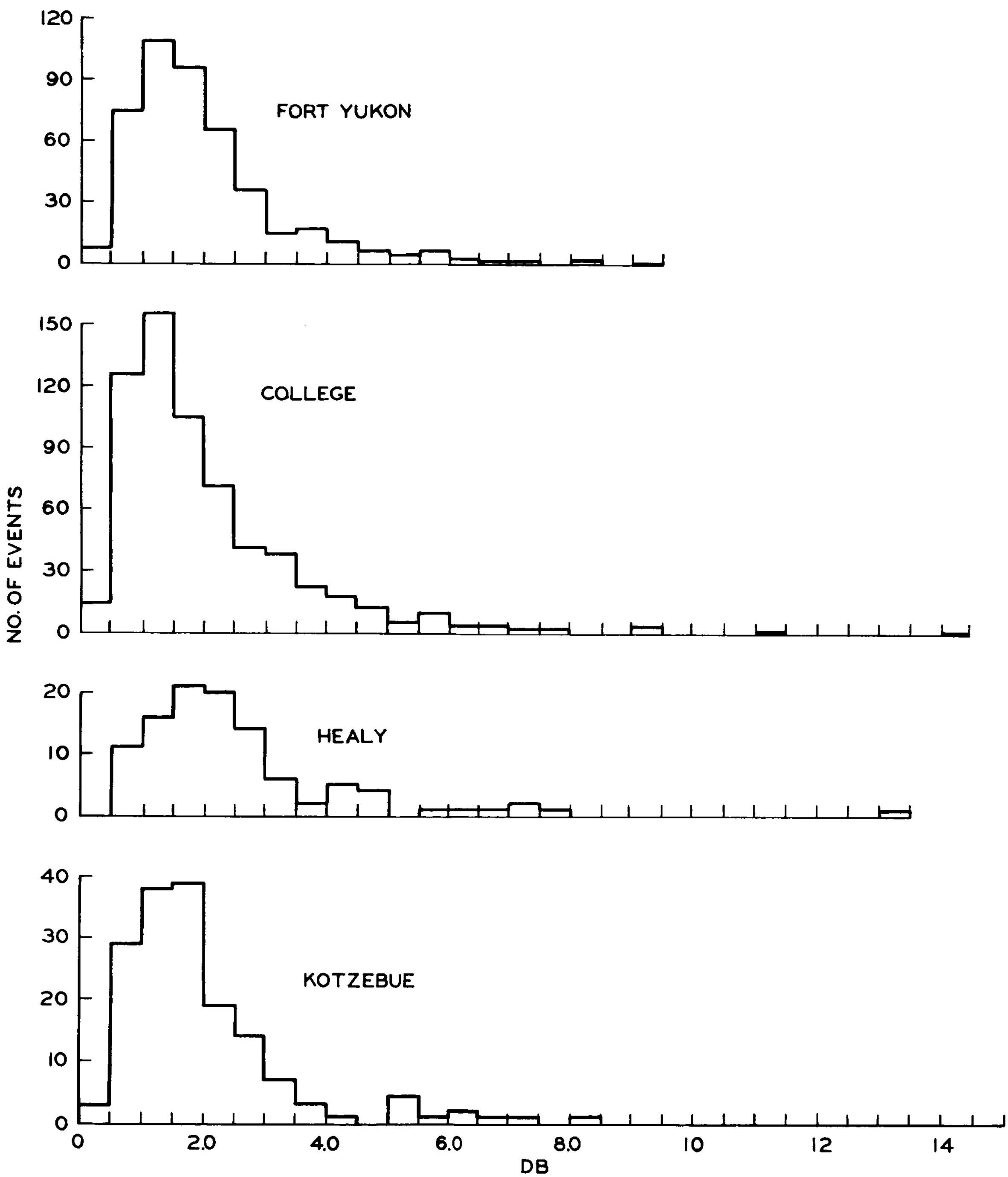

Fig. 5 The amplitude distribution of Type F_f absorption events. This graph represents the magnitude of the sudden increase in absorption measured from the predisturbance level. Note that events of magnitude <0.5 db were detectable, but infrequently observed.

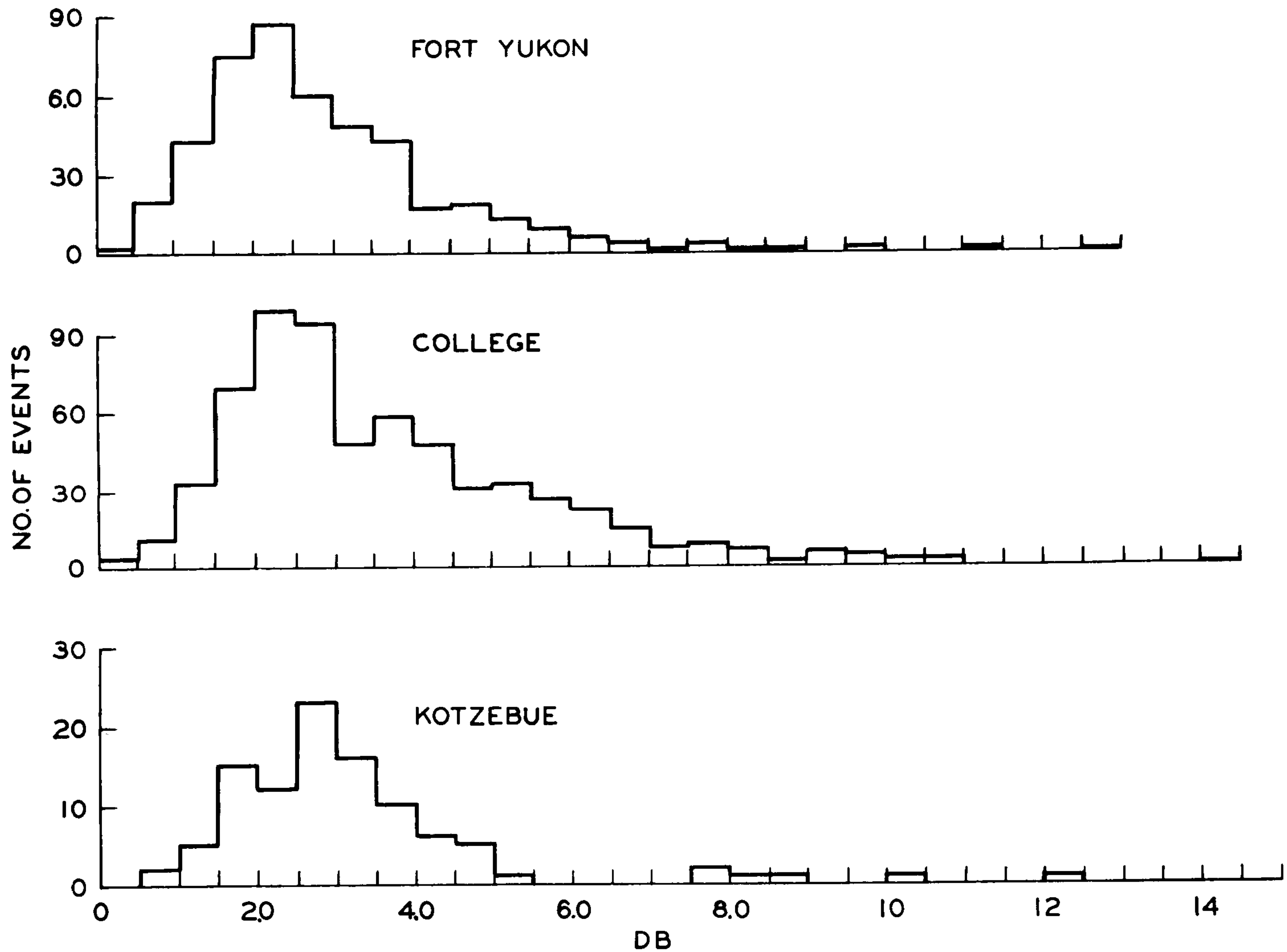

Fig. 6 The amplitude distribution of Type F_t absorption events. This graph represents the magnitude of the sudden increase in absorption measured from the quiet-day curve.

The amplitude distribution of Type F events for which the initial(i.e., pre-flash) absorption was less than 0.6 db (to be designated QF) is shown in Fig. 7. This distribution matches the ones obtained using all the data (Fig. 5). However, the occurrence of Type QF events varied from station to station. The fraction ratios of Type QF to Type F for each station are tabulated in Table 2. A latitude dependence can be inferred from this result as the ratio decreases toward the equator. This is not incompatible with the more frequent occurrence of auroral forms north of College [see, e.g. Davis (1962)] .

The data was not divided into day and night distributions in the manner of e.g. Brown (1964), who has considered the same type of events. Such an analysis has often led, in the past, to questionable conclusions. For vigourous presentations of the arguments supporting the several conclusions that can be drawn, reference may be made to Reid et al. and Hultquist (1964). We only point out that radio-wave absorption is dependent upon three factors: (a) the particle flux above a certain energy level, (b) the shape of the energy spectrum above this certain energy, and, (c) the effective recombination coefficient which varies with height and solar illumination. In the light of the present knowledge of factors (a) and (b), it seems rather arbitrary to attribute changes of the absorption level solely to factor (c). Lerfald, Little and Parthasarathy (1964), using multiple frequency cosmic-noise data, have eliminated factor (a) and inferred that either the energy spectrum is harder during the

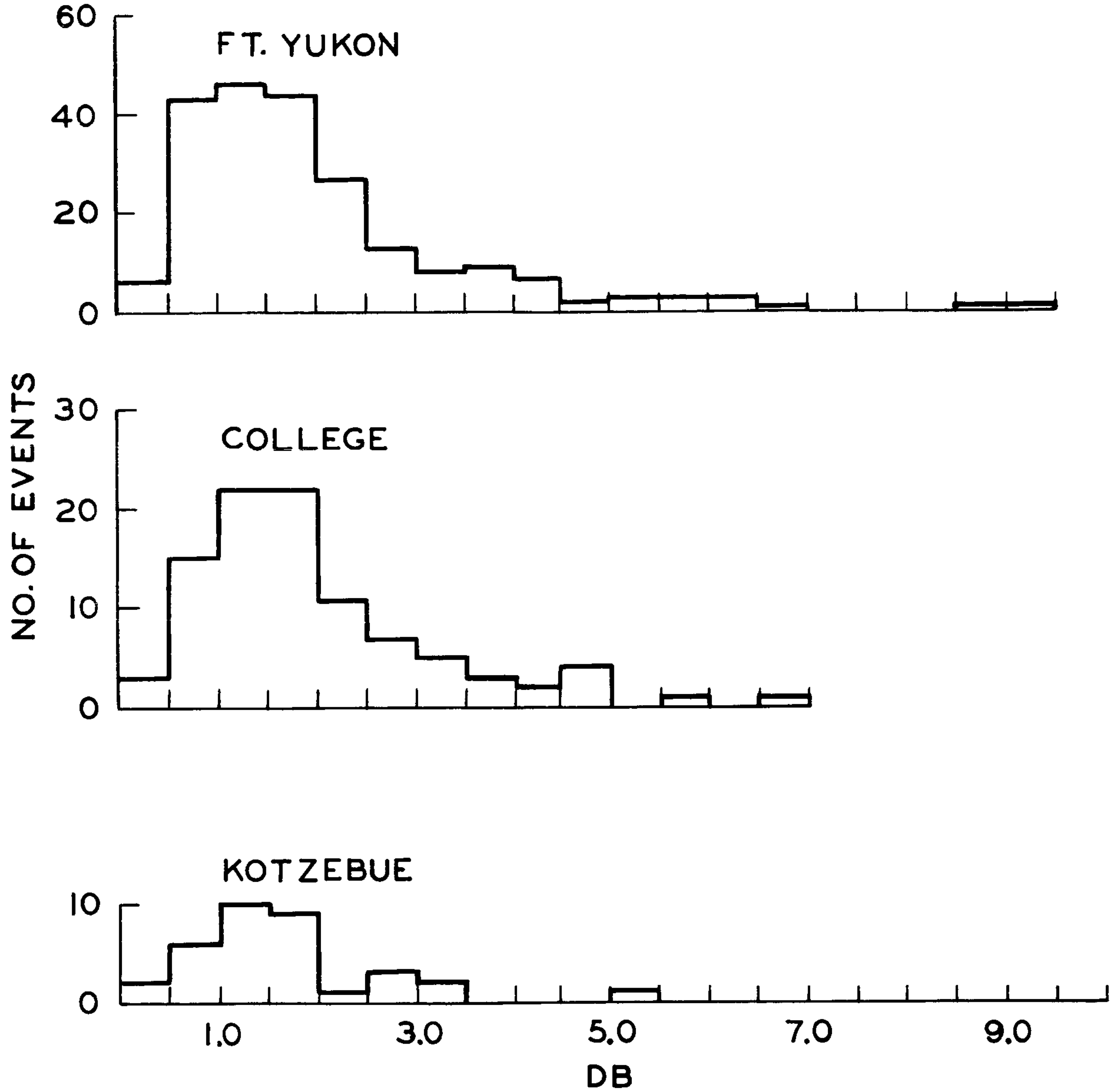

Fig. 7 The amplitude distribution of Type QF absorption events. This graph represents the distribution of Type F_f events for which the initial or pre-disturbance absorption was less than 0.6 decibels.

TABLE 2

	Type F	S	P	No. of events	QF/F
FORT YUKON	0.91	0.03	0.06	504	0.47
COLLEGE	0.85	0.09	0.05	697	0.16
KOTZEBUE	0.81	0.18	0.01	194	0.22
HEALY	0.66	0.22	0.12	128	0.12
MACQUARIE	0.41	0.55	0.04	27	-

Percentage of occurrence of the different types of events. The last column represents the percentage of Type F events which developed from quiet conditions.

day or that the day-night difference can, in fact, be attributed to the change in the recombination coefficients, if equal fluxes were considered.

2.3 Type S Absorption Events

The smoothly varying absorption bays, Type S, occurred with less frequency than the Type F events. As seen from Table 2, Type S events were relatively common at Kotzebue and Healy, but uncommon at Fort Yukon. This suggests that the Type S events favor the lower latitude stations; however, a southern boundary cannot be determined from this study. Typical absorption bays are shown in Fig. 8.

All available data from each station were combined to make the seasonal variations with the justification that the data were collected during years of similar sunspot conditions, i.e., sunspot minimum. The seasonal variation depicted in Fig. 9 indicates that no seasonal trend exists for any station. Also, no persistent pattern is outstanding between any pair of stations.

The daily variation, derived by plotting the time of maximum absorption for each event, is shown in Fig. 10. The predominate feature of these variations is a maxima near 0400 hours local time for all stations but Fort Yukon. A secondary maxima occurred near 1900 local time at College, primarily during the summer months.

The work of Ziauddin (1961) (see section 3.1) supports this result as he found a tendency for absorption bays to occur during the predawn hours.

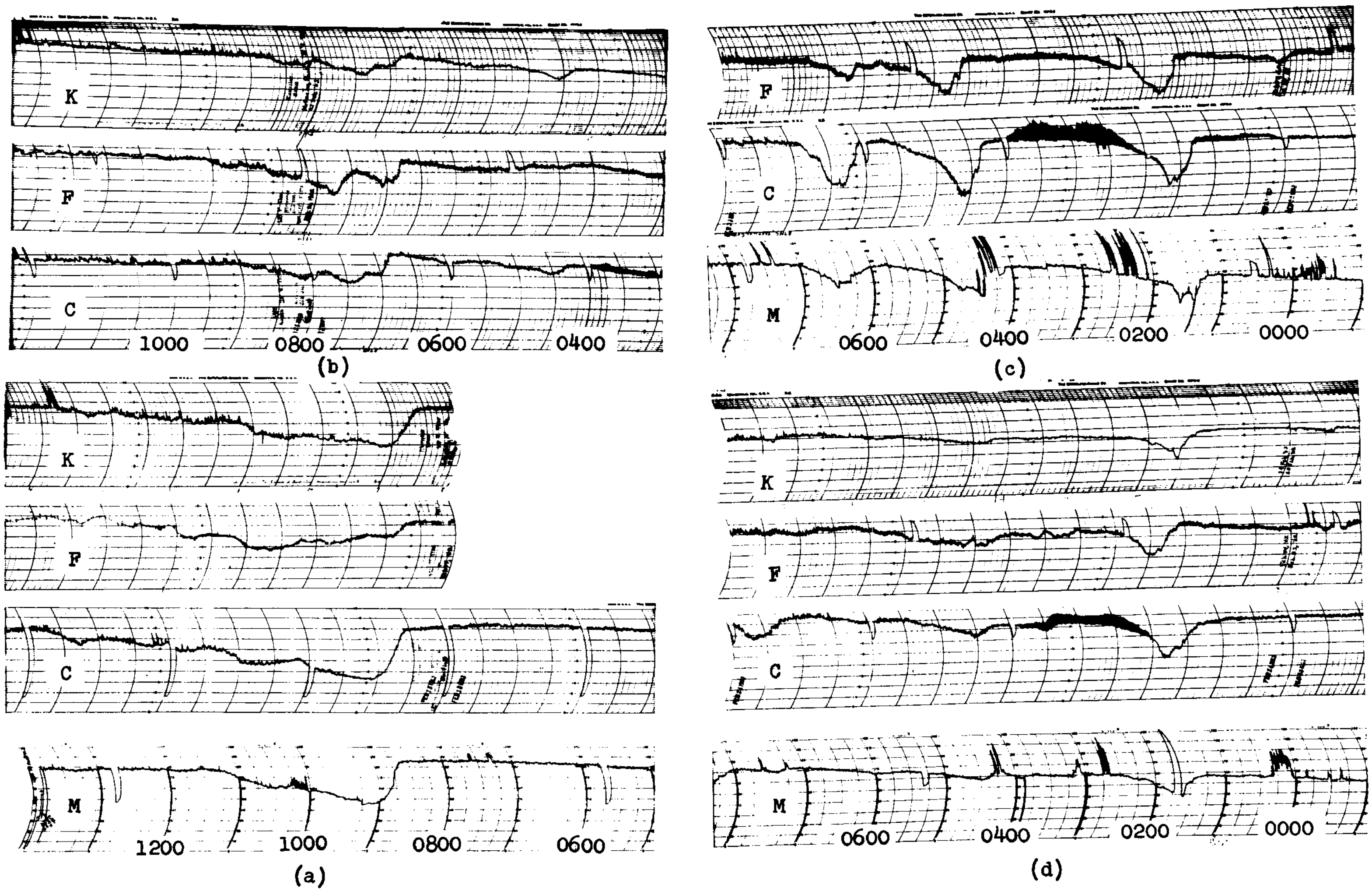

Fig. 8 Typical absorption bay (Type S) events occurring simultaneously at Kotzebue (K), Fort Yukon (F), College (C), and, Macquarie Island (M). The time is in 150° WMT. The dates of these events are: (a) Feb. 18, 1962; (b) Feb. 21, 1962; (c) Feb. 23, 1962 and; (d) Feb. 24, 1962.

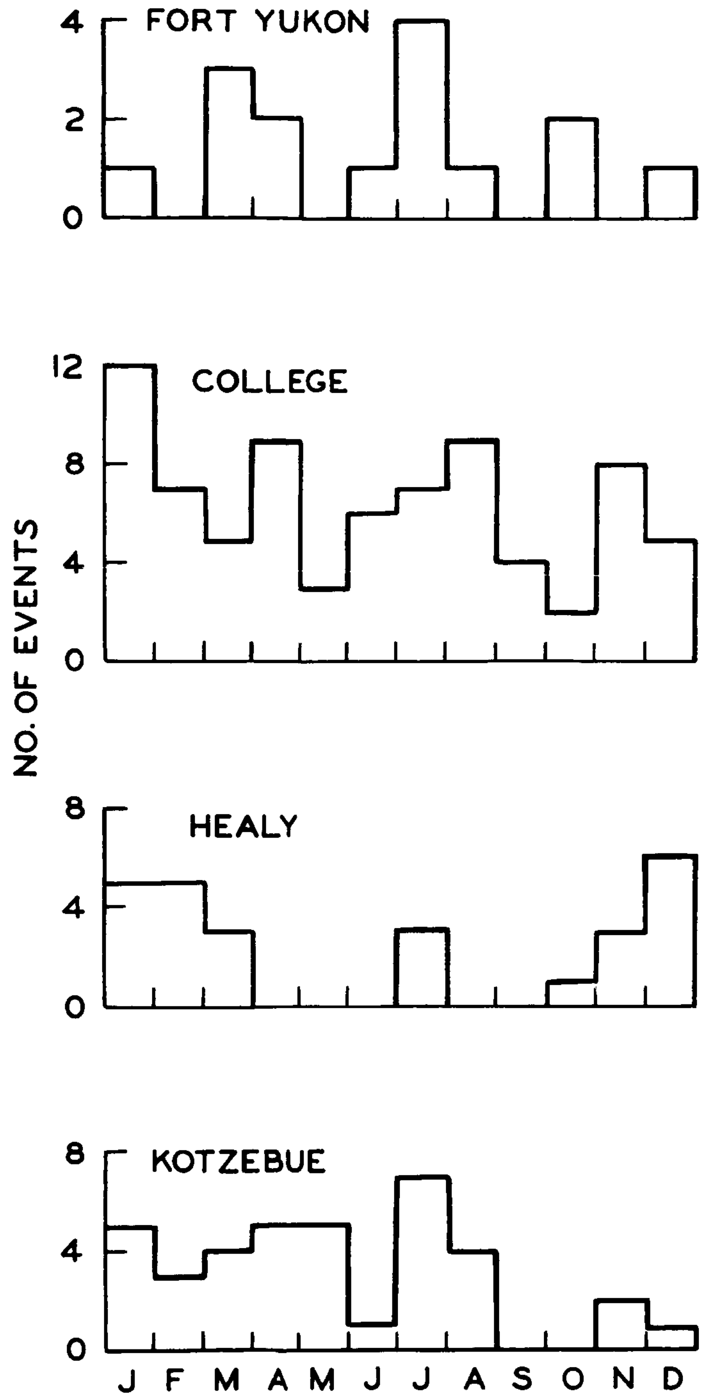

Fig. 9 The seasonal variation of Type absorption events.

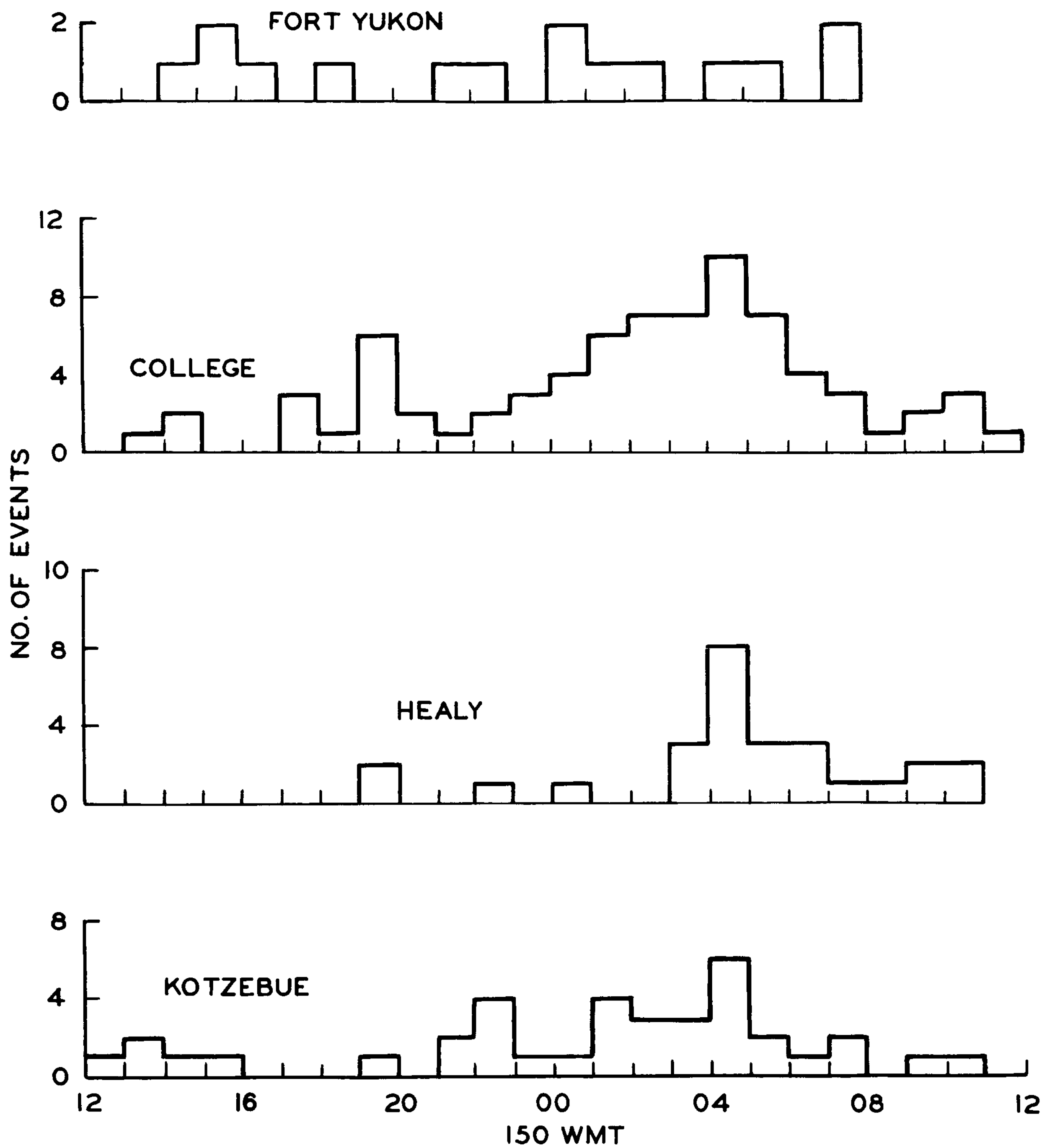

Fig. 10. The daily variation of Type S absorption events. The time of the event was taken to be the time at which maximum absorption occurred.

The possibility of photodetachment during predawn hours playing any role in the occurrence distribution was easily ruled out by reference to the sunrise tables.

The amplitude distribution for the Type S events (Fig. 11) is similar to that found for Type F events in that the Healy and Kotzebue distributions are 0.5 db greater than those for College and Fort Yukon. For all stations, the maximum amplitude is approximately 0.5 db higher than that for Type F events. It should be mentioned that as the selection criteria for Type S events was a lack of preceding of succeeding absorption activity, all events developed out of essentially quiet-day conditions. Therefore, the absorption as measured from the pre-onset level differed only to a negligible extent from that measured with respect to the "quiet-day curve."

2.4 Type P Absorption Events

The pulsating absorption events were found to be the least frequent of the events studied in this investigation. At least a part of the infrequent occurrence of these events is felt to be due to the selectiveness with which the events were extracted from the absorption records. Variations which may be interpreted as pulsations occur very often on auroral absorption records. However, the instances for which the pulsations show a very definite periodic structure are very uncommon and it is those instances which have been chosen for study. Fig. 12 illustrates such a Type P event.

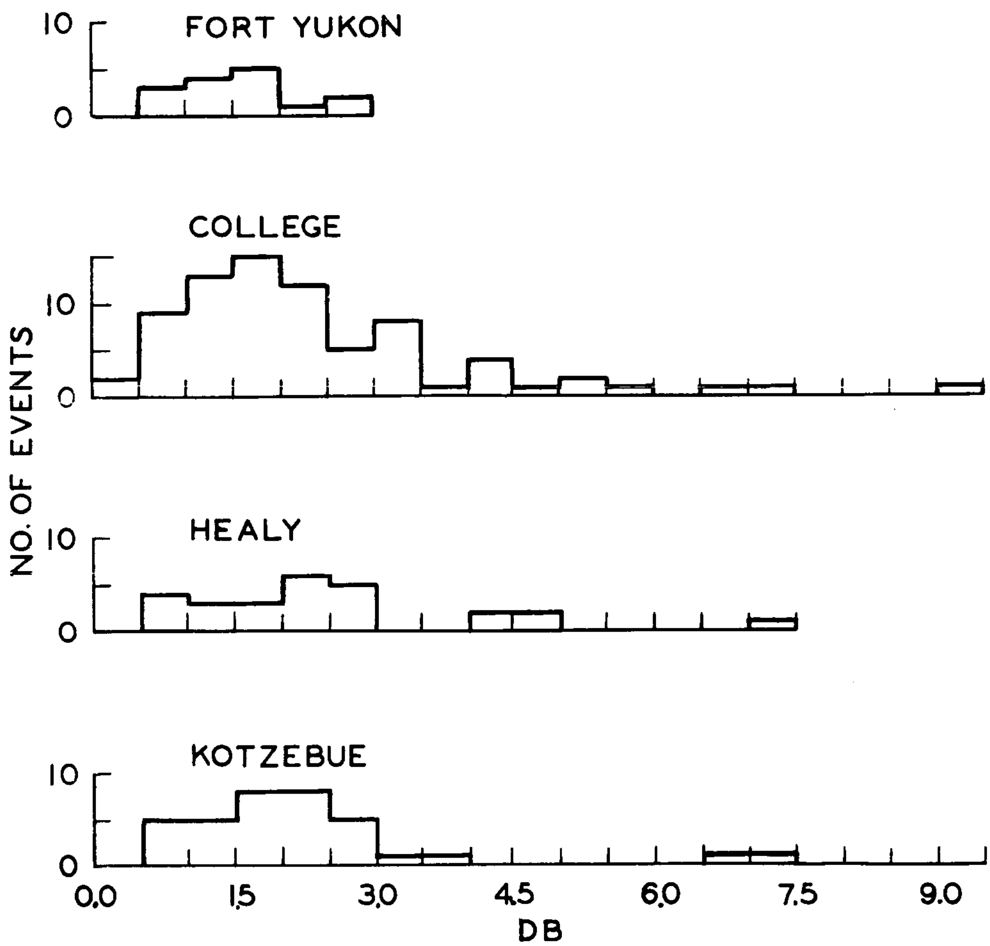

Fig. 11 The amplitude distribution of Type S absorption events.

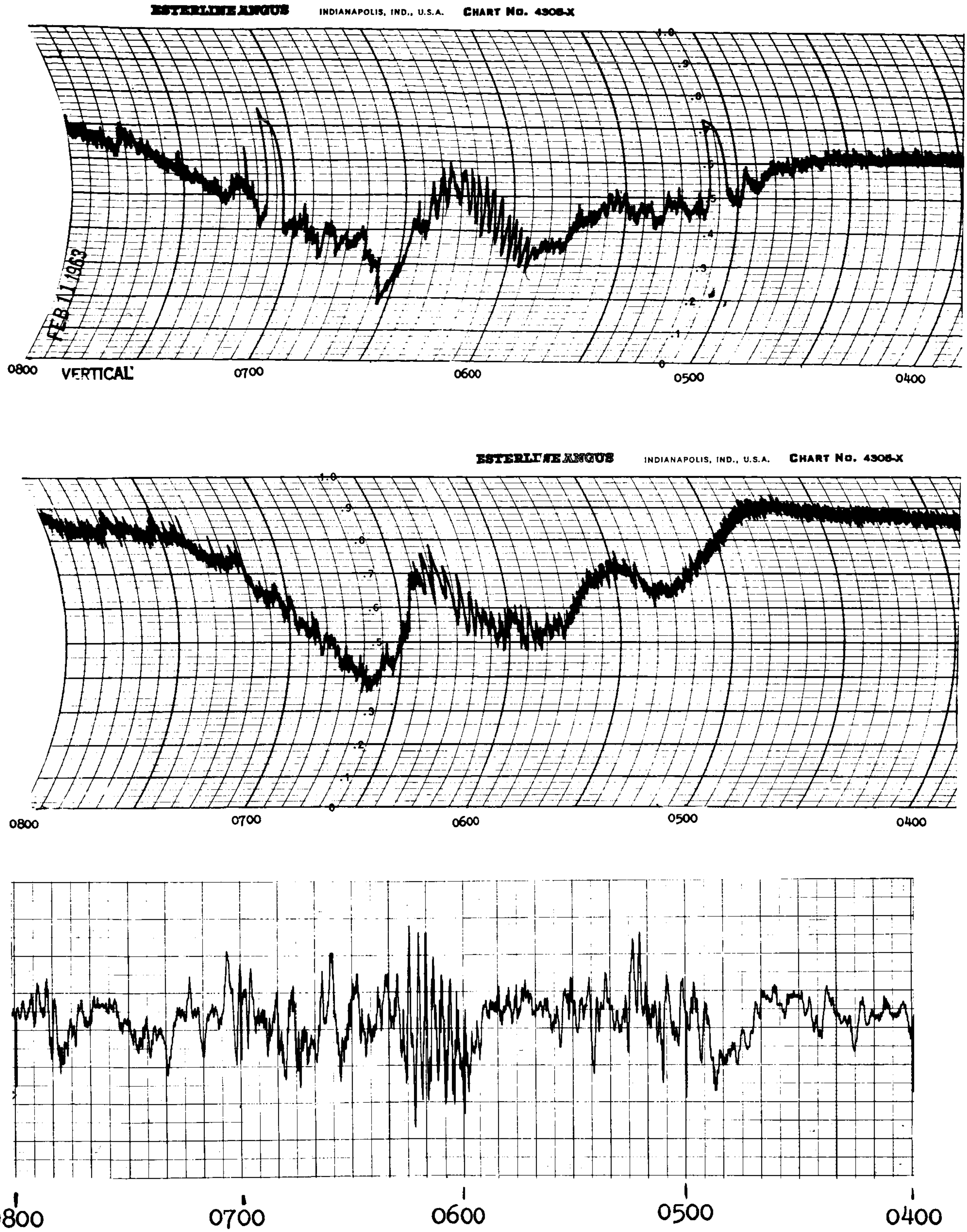

Fig. 12 An example of sustained, periodic variation of radio-wave absorption at 27.6 Mc/s at College (top) and Healy (middle) and the earth current record from College (bottom). The period = 2.5 minutes (after Parthasarathy and Hessler, 1964).

The seasonal variations, shown in Fig. 13, do not show a trend at any one station or between any pair of stations. Perhaps the only outstanding feature is a summer minimum.

The daily variation shown in Fig. 14 represents the number of half hour periods during which pulsating absorption was observed. Most of the pulsating events were observed for more than 30 minutes.

The daily variation at Fort Yukon has a broad maximum in the early morning hours following midnight, while the maximum at College is centered around 0600 local time. A secondary maxima occurs in the early afternoon hours. At Healy, the morning maxima is centered about 0700 local time. It is also of interest to note that during every one of the events noted, there was no difference in the periods between Healy and Fort Yukon, situated at different latitudes. Simultaneous data covering a larger range of latitudes may help to confirm that the period is independent of the latitude, unlike the case of the hydromagnetic oscillation whose period increases polewards.

The amplitude distribution (Fig. 15) was derived by measuring the maximum amplitude of each pulsating event. The resulting distribution seems to match the distribution found for Type F events although the amount of data is much smaller.

In determining the period of the pulsating events, it was found that no single preferred period was found. The range of periods extended from two minutes to 12 minutes. No pulsations of periods less than two minutes were observed, although such pulsations are within the detectable range of the cosmic noise recorders. The average period was found to be about 340 seconds.

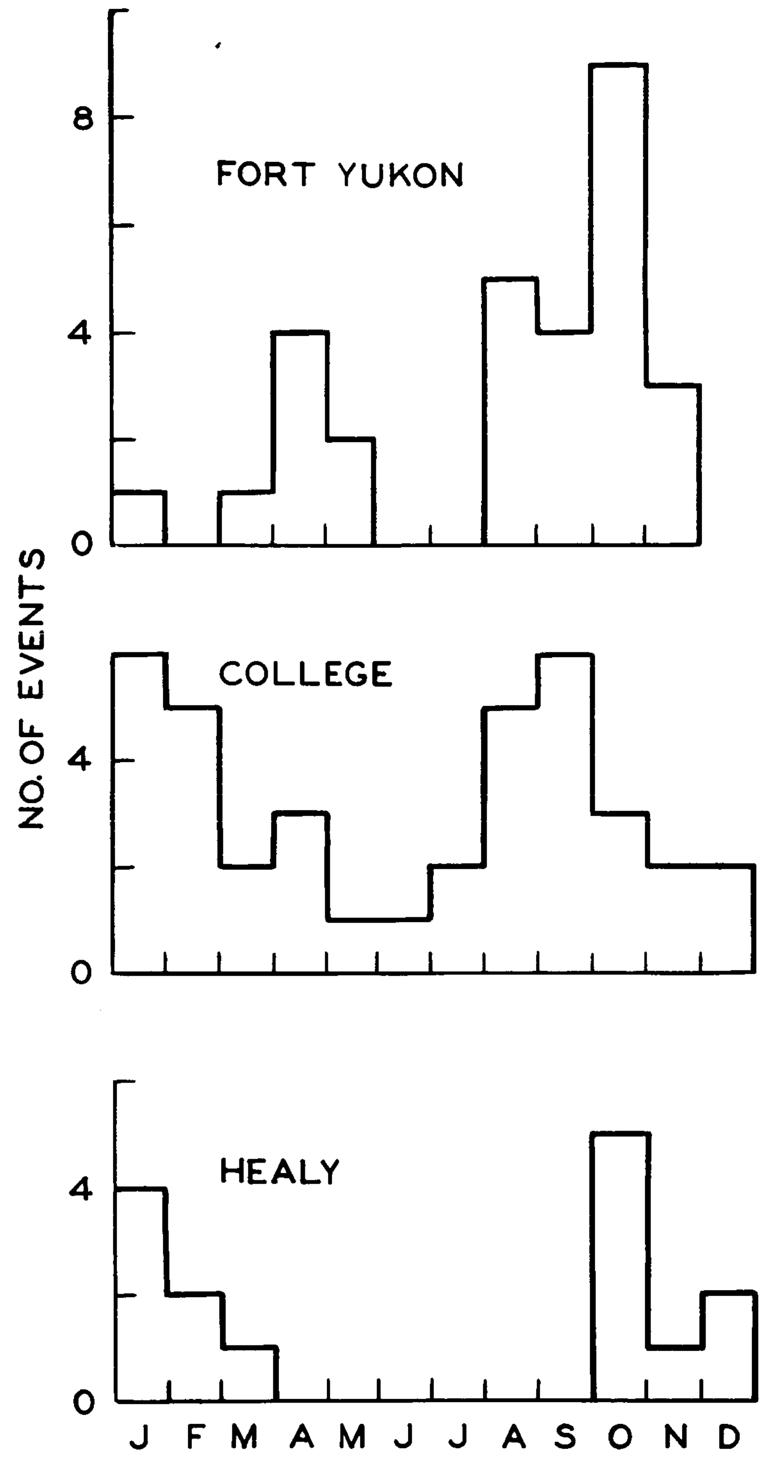

Fig. 13 The seasonal variation of Type P absorption events.

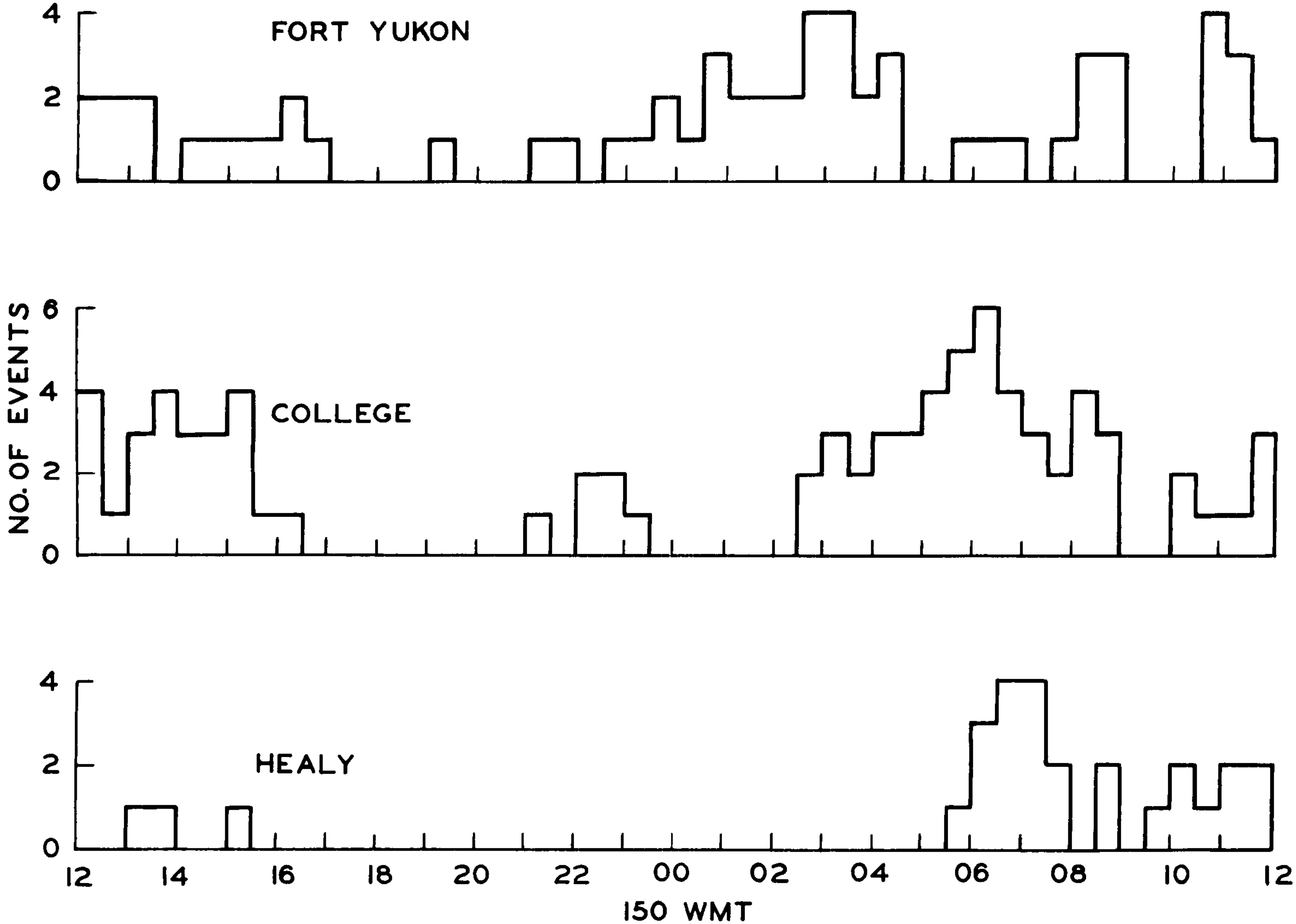

Fig. 14 The daily variation of Type P absorption events. This graph represents the number of half-hour intervals during which pulsating absorption events were observed

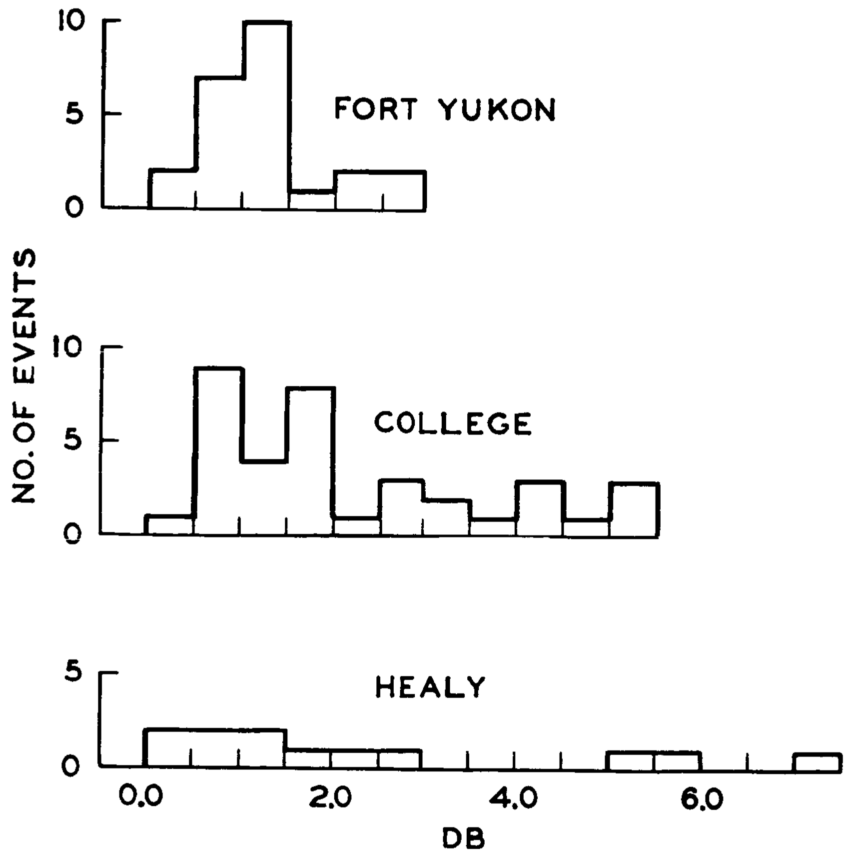

Fig. 15 The amplitude distribution of Type P absorption events. This graph represents the amplitude of the pulsating component of absorption.

CHAPTER III

CORRELATION OF ABSORPTION AND MAGNETIC DISTURBANCE

3.1 Introduction

Wells (1947), using vertical incidence ionosonde data, investigated the relationship between radio-wave absorption and magnetic disturbance. He found that absorption accompanied negative bay disturbances of the H-component. In addition, he determined that areas separated by as much as 500 miles were affected by the same bay disturbance.

Meek (1953) at Saskatoon, found the same relation between the absorption registered on the ionosonde data and negative bay disturbances of the H-component. He also related sudden increases in auroral intensity with the rapid changes of the H-component occurring at the time of onset of a bay disturbance.

Little and Leinbach (1958) using cosmic noise absorption records, were able to show that a high degree of correlation existed between the College K-indices and the peak absorption registered during the time intervals over which the K-index was obtained.

Ziauddin (1961) in his study of auroral absorption has examined the relation of absorption bays to magnetic activity. The results of his study indicate that: (a) absorption bays and magnetic bays are not invariably associated; (b) absorption bays occur in the last phases of the disturbed period of the night; (c) the onset of magnetic bays always precedes that of absorption bays and; (d) the intensity of absorption bays and magnetic bays are not related in any simple manner.

3.2 Type F Events

In order to ascertain whether a more exact relation between Type F absorption events and magnetic disturbance could be established, the H-component of the College magnetograms was examined near the time that a Type F event occurred. For these events the rapid-run magnetograms were utilized to allow for adequate time resolution. The positive or negative change of the H-component was scaled and the value plotted against the corresponding change of absorption (Type F_f). The correlation between the two parameters is very poor as can be determined from the scatter of points in Fig. 16. It was found that the rapid-run magnetogram records were often difficult to interpret due to the numerous changes of the trace. Hence, one must be careful in attributing the positive changes of the H-component to sudden commencement phenomena.

The lack of correlation found here agrees with the results of Fedyakina (1963) who was unable to find any correlation between 20 minute averages of absorption and an hourly magnetic index. The same result was obtained by Ziauddin (1961) for Type S absorption bays. His scatter plot of absorption intensity against magnetic intensity shows little or no correlation. It has been suggested for further study that the change in the total field should be compared with the change in absorption.

The preceding study has shown that the change of the H-component associated with the Type F event was itself invariably associated with a negative bay disturbance. In view of the close connection, the daily distribution of Type F events may be

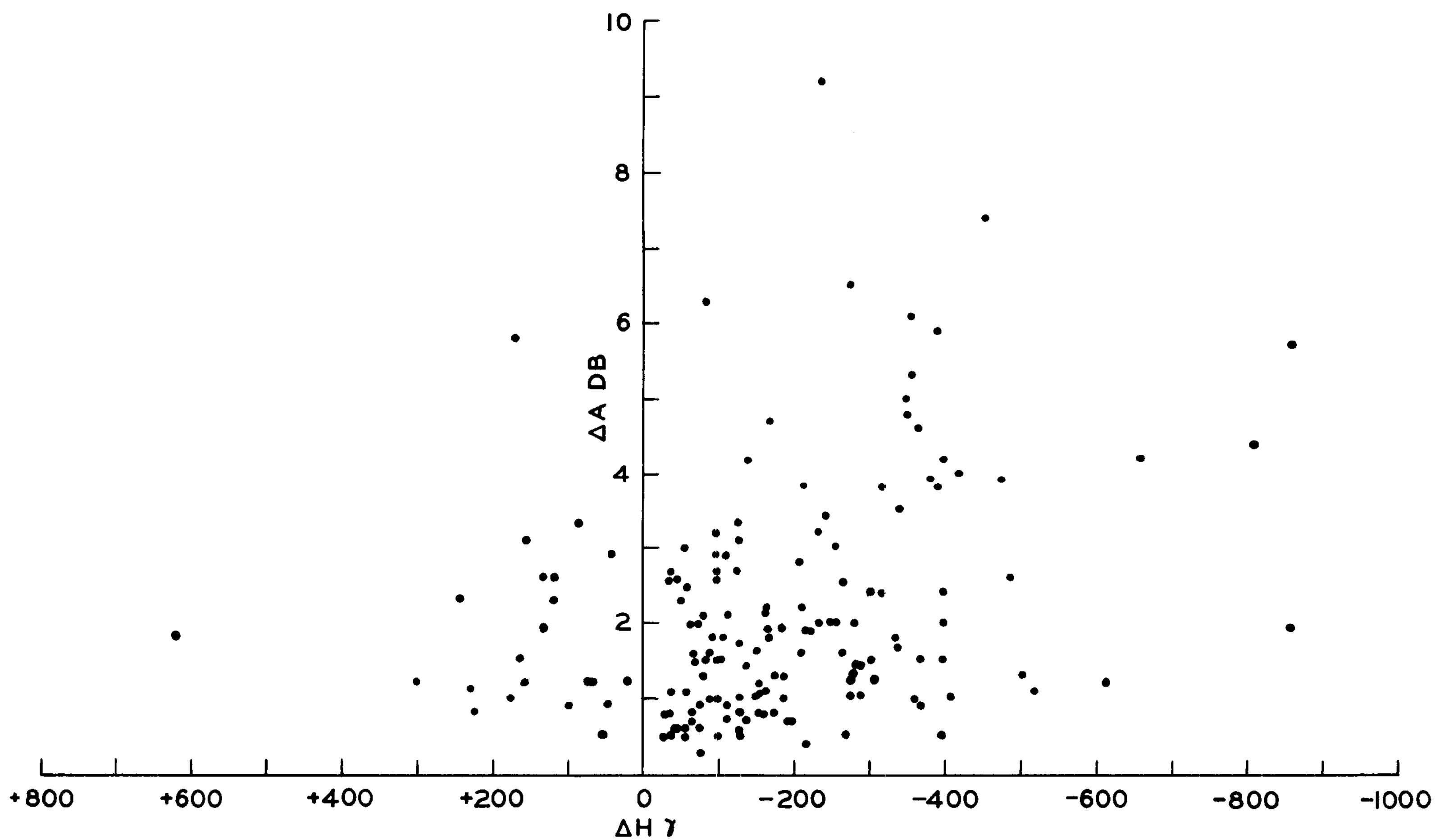

Fig. 16 The absorption magnitude of Type F_f events at College plotted against the corresponding changes in magnitude of the H-component of the College Magnetogram. Data from 1962 were used in this study.

compared with the local time distribution of occurrence frequency of broad negative bays as found by Oguti (1963) for polar magnetic disturbances. He found a maximum frequency of occurrence following local midnight. Additional support is found in the work by Romana and Cardus' (1962) who have determined that the probable time of maximum occurrence for negative bays in the auroral zone is 24.1 hours local time. In addition, neither variation shows any secondary maximum. It should be noted that the diurnal variation of the mean magnetic K-index for College in 1954 as determined by Little and Leinbach (1958) has a similar shape.

The converse proposition of whether every negative bay is connected with a Type F event was not investigated in detail; however, cases are known where negative bays did not have a corresponding Type F event.

The insensitive or storm-time trace of the magnetic disturbance accompanying the Type F event of Fig. 1 is shown in Fig. 17.

3.3 Type S Events

Type S events were also found to accompany bay disturbances. The early morning events accompanied negative bay disturbances while those occurring before 2300 local time accompanied positive bays. Of the events studied, less than 10% were found to be accompanied by no magnetic activity at all. The percentage was somewhat higher at Kotzebue, but that station lies near the boundary of the region predicted by Wells to be affected by local magnetic disturbance. The daily variation of these events does

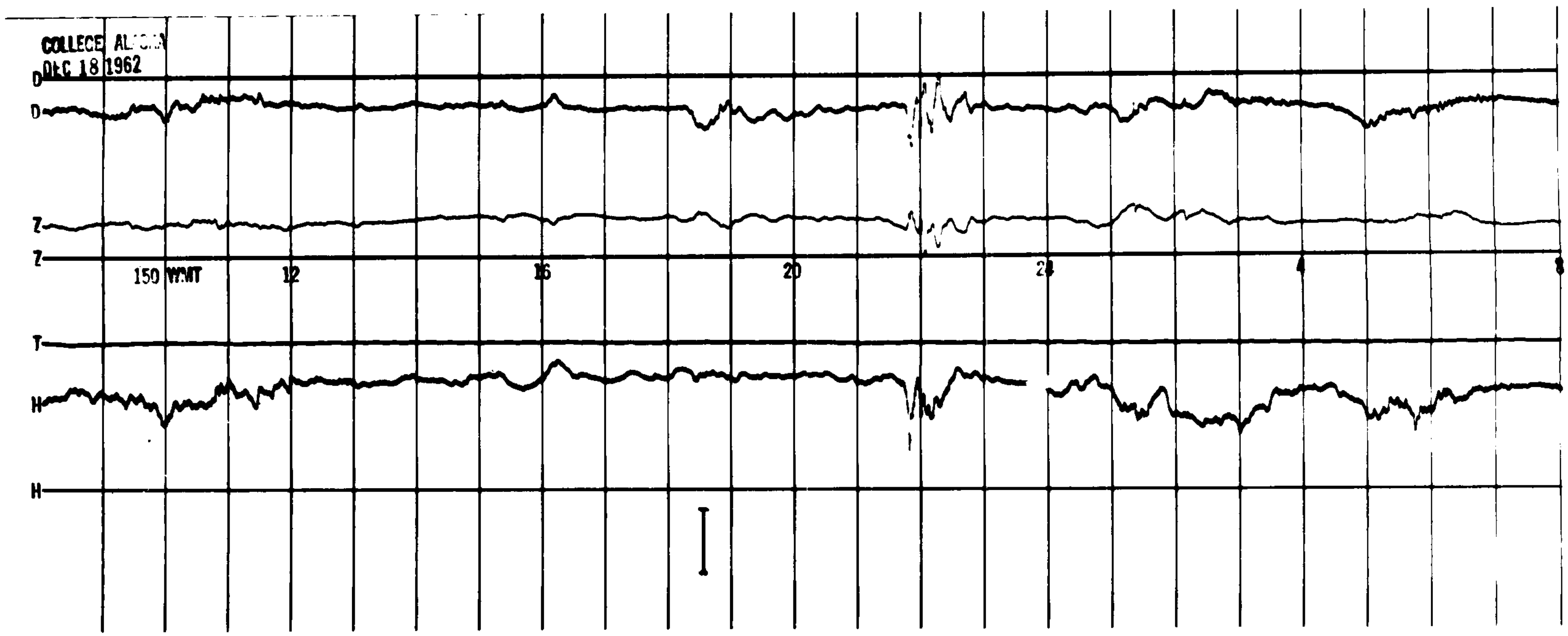

Fig. 17. The Insensitive Magnetogram record for the absorption event of December 18, 1962, which is depicted in Fig. 1. Note that time increases to the right on the Magnetogram record. The scale represents 500γ.

not seem to match that found for bay disturbances except for the secondary maxima in the early evening hours. These events seem to occur at about the time of maximum occurrence of positive bays which various authors have placed between 16 and 21 hours local time.

3.4 Type P Events

As mentioned previously, Ziauddin (1960, 1961) and Anger et al. (1963) have found coincident variation occurring between the H-component and absorption records. For a number of the events considered here, pulsations were observed simultaneously on either the H or D component traces of the magnetograms. However, the magnetogram variations were often found to be out of phase and in some cases did not accompany absorption pulsations at all. Regular pulsations are a common feature of high-latitude magnetograms, whereas absorption pulsations are very infrequent. Hence, the relationship between geomagnetic and absorption pulsations is unclear.

However, a comparison of the features of geomagnetic pulsations with periods of the same order as those found for absorption pulsations indicates that some correlation may be possible. Kato and Saito (1962) have divided geomagnetic pulsations into three types (dependent upon period) and investigated each type. The two types of interest in this study are Type II of period 50-150 seconds and Type III of period 150-900 seconds. Not enough Type P absorption pulsations were observed to warrant such a classification. The geomagnetic pulsations of Type III occur most frequently in the afternoon and early morning hours. A noontime maxima is found for the pulsations of shorter period (Type II). Pulsating absorption events occurred most frequently in the early morning hours and had a secondary maxima near noon. Further study of Type P events utilizing more data and perhaps less stringent selection criteria will be of value in investigating this relationship further.

CHAPTER IV

RADIO-WAVE ABSORPTION AND VISIBLE AURORA

4.1 Introduction

The problem of relating radio-wave absorption from narrow beam antennas with visual auroral forms has received considerable attention at College by Ansari, Leinbach and Parthasarathy. The details may be seen in Ansari (1963) who examined the relation between luminous auroral forms and the various phases of aurorally associated absorption that are distinguishable during an absorption event. Pertinent especially to this study was his detailed examination of sudden absorption increases (Type F) and the corresponding all-sky camera and photometric data. He found that the Type F events could be classified into uniform non-uniform, or localized events and that study of the localized events yielded the best information concerning the relation of absorption to luminous aurora. He was able to conclude that strong absorption was limited to the regions of bright and active auroral displays during the breakup phase, but that the relationship became more complex following this period. The statistical validity of these inferences (e.g. through the use of scatter diagrams) could not be established due to the uncertainties in the amount of noise power entering through the side lobes of the antennas.

The College all-sky camera data were examined in conjunction with the three types of events under consideration in this study. Since the 100 kilometer region above each field site can be seen by the College all-sky camera, absorption events occurring at each station were compared with the all-sky film.

Fig. 18 is useful in interpreting the all-sky camera data. The geometric figures represent the projection of the antenna patterns at the half-power points at the 110 kilometer level above each field site onto the field of view of the College all-sky camera film. The cross marks on the north-south and east-west axes (geomagnetic) represent the positions of the indicating lamps as seen on the film. A scale indicating the angular distance from the zenith is included for reference.

In view of the detailed study of Ansari (1963), which incorporated many of the specific events (Type F) studied here, the discussion of the relation of Type F events to the visible aurora will be kept to a minimum.

4.2 Type F events and their relation to luminous aurora

4.2.1 Discussion of the breakup event of January 26, 1962

The association between a typical Type F absorption event and auroral activity is depicted in Fig. 19. Prior to 2335 hours local time (note that all times will be given in 150 WMT), two quiet arcs were seen, one about 30° south of the College zenith and another close to the northern horizon. At 2336, the arc south of the zenith moved rapidly into the zenith and increased several-fold in intensity. During the period from 2337 to 2340, the arc appeared to move northward, filling the sky north of the zenith with moving forms. After 2340, an arc appeared near the northern horizon approximately above

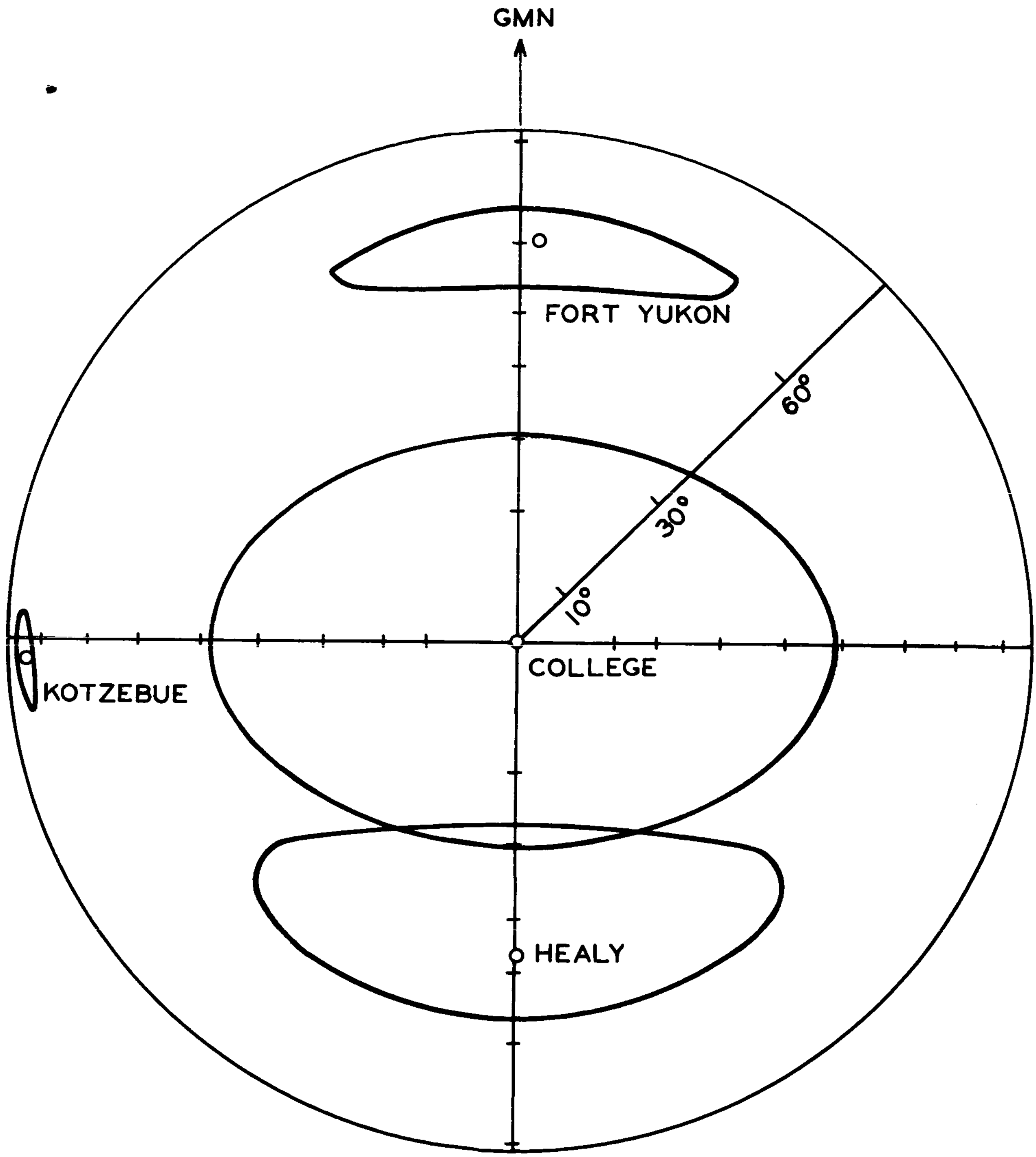

Fig. 18 The geometric figures represent the projection of the antenna patterns at the half-power points at the 110 km level above each field site onto the field of view of the College all-sky camera. The cross-marks on the north-south and east-west (geomagnetic) axes locate the positions of the indicating lamps, as seen on the film. A scale denoting angular distance from the zenith is included for reference.

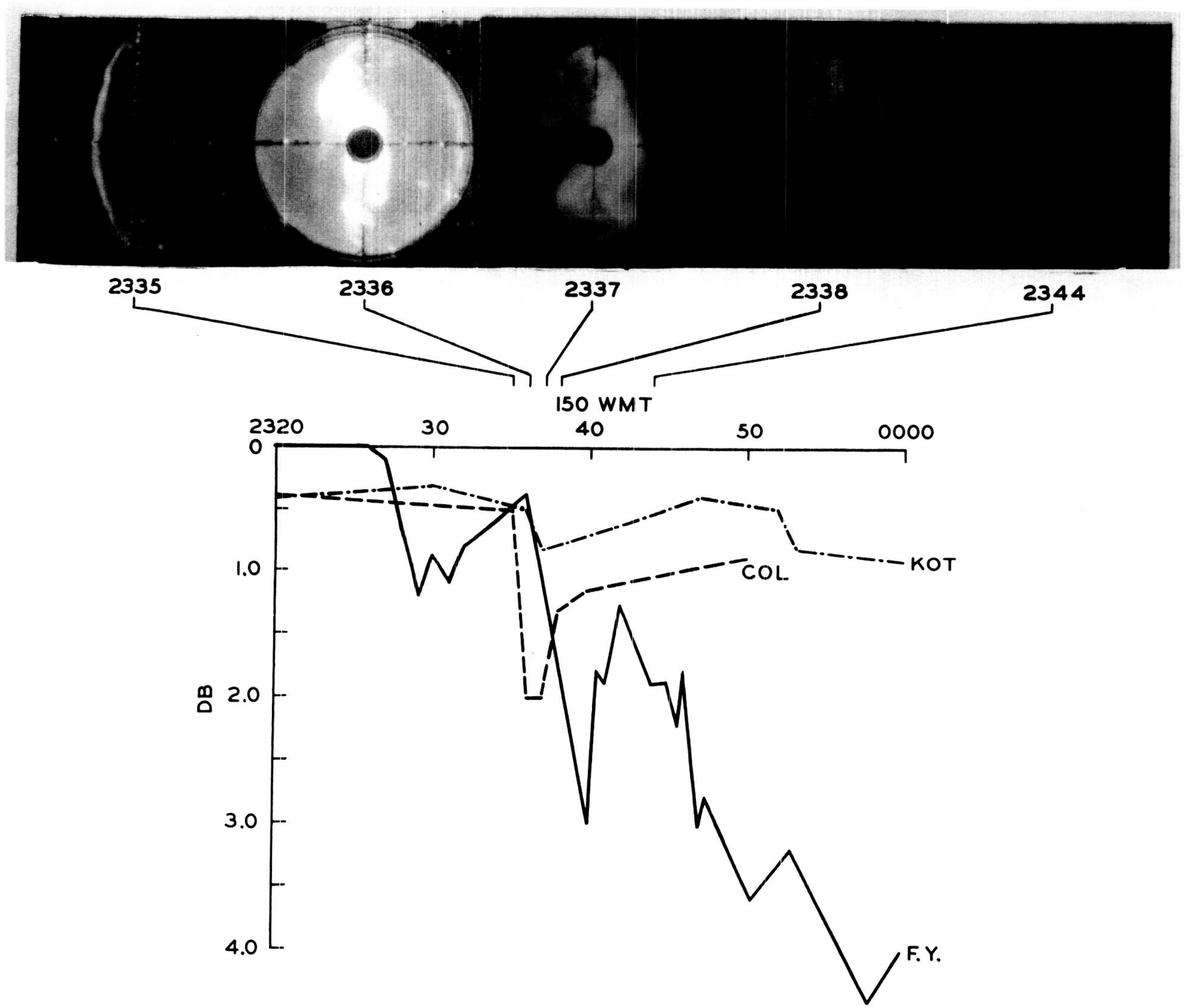

Fig. 19 The breakup event of Jan. 26, 1962 and the associated Type F absorption event.

Fort Yukon and diffuse auroral forms were seen covering the remainder of the sky. Motion and intensity changes were noted in this arc for the next hour.

Before 2335 and during the period when the quiet arc was seen, the absorption at College registered approximately 0.5 db. At the time of breakup, when the rapid northward motion and increase in intensity was observed, the absorption increased 1.7 db. Recovery to nearly pre-disturbance conditions followed the breakup, after which time no distinct auroral forms were observed within the antenna pattern.

At Fort Yukon, the sudden increase of absorption associated with the breakup was not observed until 2337 at which time the active auroral forms had moved into the region being monitored by the cosmic noise receiver. Recovery was not complete due perhaps to the active arc which remained approximately over Fort Yukon.

Only a small amount of absorption was registered at Kotzebue, perhaps due to the absence of active auroral forms within the antenna pattern. The absorbing region accompanying the active arc may have moved from this region due to the rapid poleward expansion of the arc.

Based on many examples such as that shown in Fig. 19, marked brightening of the visual auroral form and the sudden increase in cosmic noise absorption seem to be inseparably connected. It is, however, not necessary that the actual absorbing region be confined to the auroral altitudes of ≈ 110

to 120 km. Single frequency absorption data does not throw much light on the location of the main absorbing region (see Chapter 6).

4.2.2 Latitude distribution of Type F events

The latitude distribution of Type F events may be consistent with Akasofu's (1964) model of the auroral substorm. During the expansive phase, stage II (T = 5-10 minutes) he has found that the brightening of an arc is followed by its rapid poleward motion, thus giving rise to a bulge around the midnight meridian. Therefore, depending on the initial position of an arc, the absorption increase corresponding to the sudden increase in brightness may be seen at say, College and then Fort Yukon, but not at Healy. If during the sunspot minimum the equatorward limit of auroral arcs was normally near College, then College and stations to the north of College should observe more Type F events than stations south of College. Such was the case during this study.

The rate of poleward expansion was found by Akasofu to be dependent upon the intensity of the disturbance. Large disturbances, when the southern-most arc first brightens, expand most rapidly (up to 200 km/min). This rate of expansion would explain the often observed time delay between events at College and Fort Yukon. Similarly, when an event was recorded at all stations, there was little or no time delay observed.

4.3 Type S events and their relation to luminous aurora

Absorption bays, which were found to occur most frequently in the pre-dawn hours (see Fig. 10) are correlated with the break-up process of arcs near the dawn meridian. Akasofu (1964) has found that during the expansive phase, stage III ($T = 10$-30 minutes) of an auroral substorm, when active auroral bands appear around the midnight meridian, arcs appearing near the dawn meridian become brighter, move slightly equatorward and then breakup <u>without</u> violent motion. The breakup results in cloud-like, isolated patches which drift eastward toward the twilight meridian. Another characteristic feature of the auroral arc at this time is the eastward drift of the so-called Ω band. This sequence of events can be followed in Figs. 21 and 23. The absorption bays accompanying these auroral break-ups are illustrated in Figs. 20 and 22.

From analysis of all-sky camera data, Akasofu (1964) has concluded that the breakup of quiet arcs into patches near the dawn meridian does not occur often poleward of the auroral zone and is in fact most prevalent equatorward of the auroral zone. This result is in agreement with the latitude variation of absorption bays found in the cosmic noise records. Few absorption bays were observed at Fort Yukon, near the center of the theoretical auroral zone, while the most common feature at both Healy and Macquarie Island, somewhat equatorward of the auroral zone maximum, was the absorption bay.

4.3.1 Discussion of the auroral breakup event of January 14, 1962

The pattern of events described by Akasofu can be followed in the College all-sky film between 0500 and 0600 local time.

A quiet arc appears approximately 60° north of the zenith until 0517 when it begins to move toward the equator, slowly increasing in brightness. The maximum brightness seemed to be spread over a period of time, in contrast with breakup events near the midnight meridian, which peaked in brightness in a few minutes. Cloud-like patches began to form at 0530 and drift eastward throughout the remainder of the sequence. The development and eastward drift of an Ω band can be followed from 0543 to 0605. The eastward drift of patches continued well into twilight.

In Fig. 20 the development of the associated absorption bay can be seen for both College, Kotzebue, and Macquarie Island. At 0430, accompanying the formation of the arc seen at 0505, the absorption increased slightly. Between 0515 and 0520, coinciding approximately with the beginning of the equatorward motion of the arc, the absorption increased at a greater rate. The absorption maxima was broad with recovery beginning near 0550. Full recovery to quiet conditions was not complete until 0800. The absorption at Kotzebue and Macquarie followed essentially the same pattern, although some details were different.

4.3.2 Discussion of the auroral breakup event of January 23, 1963

Prior to breakup an arc appeared about 30° north of the zenith. The arc remained stable until 0215 when an equatorward motion began. At 0231, patches formed and began to drift

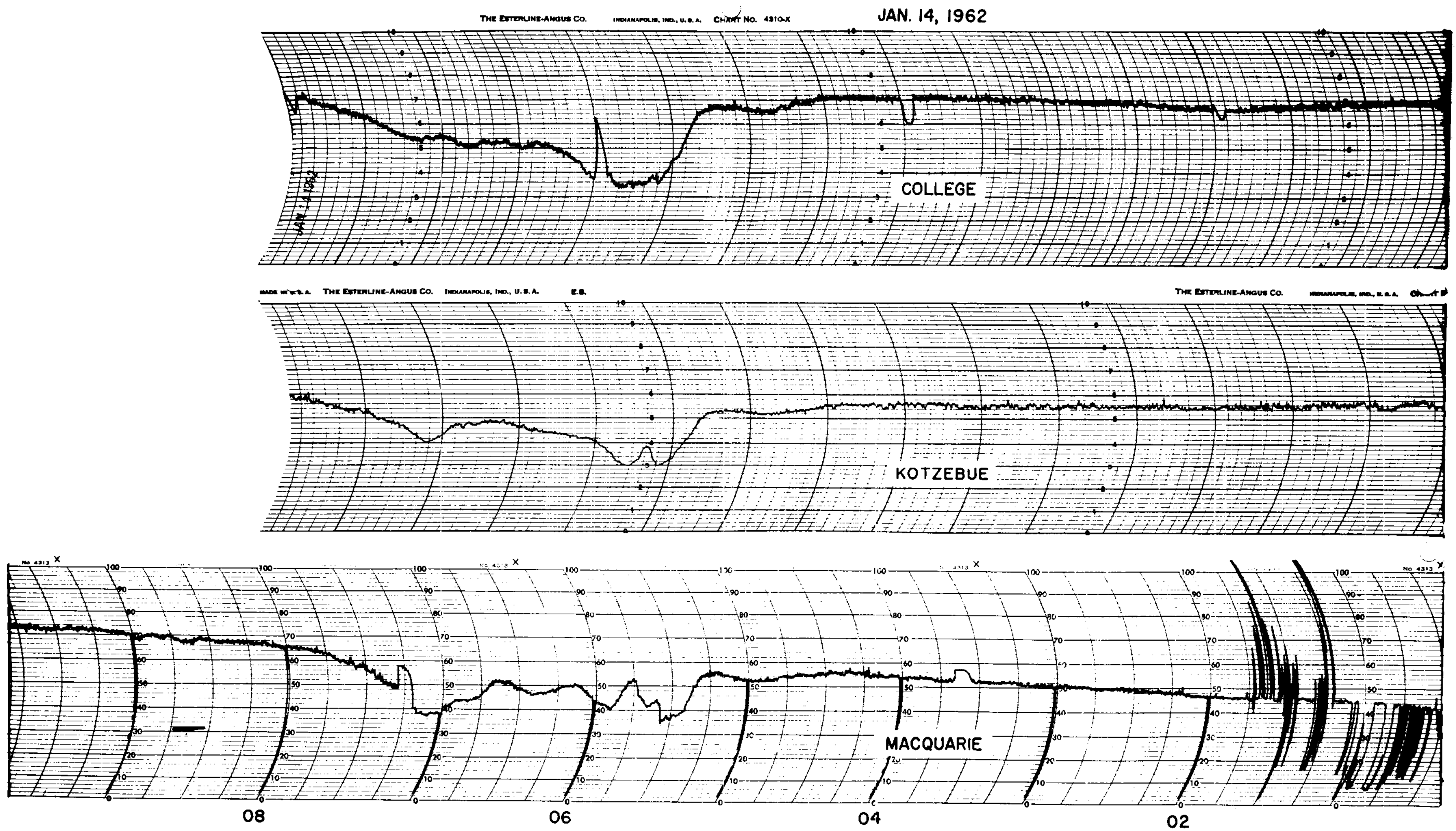

Fig. 20 Original riometer records for the breakup event of Jan. 14, 1962 showing the associated Type S events at College, Kotzebue, and Macquarie Island. Compare Fig. 20 with the all-sky photographs for this event presented in Fig. 21.

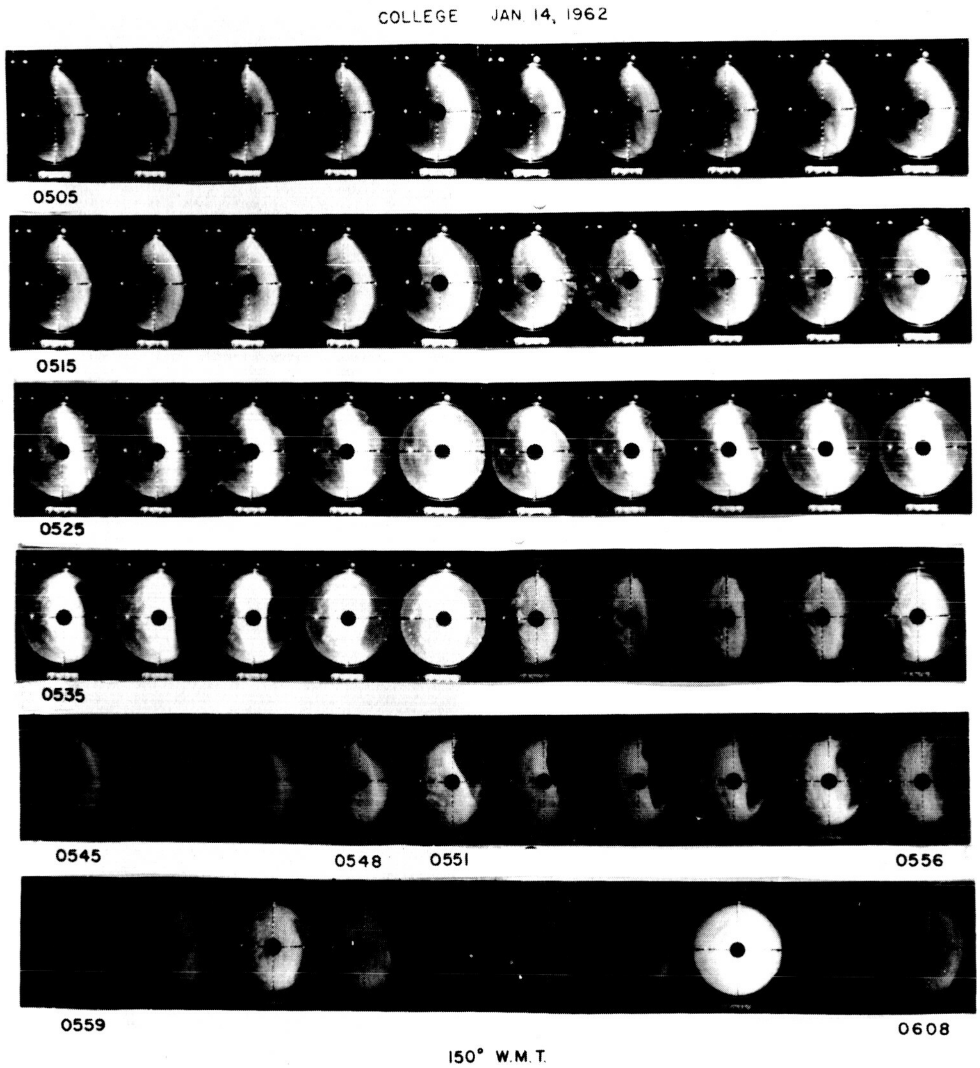

Fig. 21 All-sky photographs taken during the pre-dawn breakup event of Jan. 14, 1962. Note the eastward drift of isolated patches following the breakup period. Compare this figure with Fig. 20.

eastward. At 0223 an $\mho$ band formed and also began to drift eastward toward the twilight meridian.

At 0212 the absorption at both College and Fort Yukon began to increase (see Fig. 22) coinciding with the time of equatorward motion of the arc. At College, the recovery began about 0230 when the patches were observed to form. At Fort Yukon, the absorption maxima lasted somewhat longer. Recovery was complete by 0300. The patches had disappeared by 0304.

4.3.3 Longitudinal and latitudinal extent of absorption bays

In Fig. 24 an absorption bay associated with a breakup event of the type discussed above is presented. The latitude dependence can be inferred from this figure. Relatively little absorption is seen at Fort Yukon, while all other stations show a significantly larger amount of absorption. The longitudinal spread of absorption bays is at least 15° as nearly all bays seen at College were also observed at Kotzebue. Akasofu has found that auroral arcs often extend from Canada to Siberia.

4.4 Type P events and their relation to luminous aurora

Usable all-sky camera data were not available during periods when pulsating absorption events were recorded.

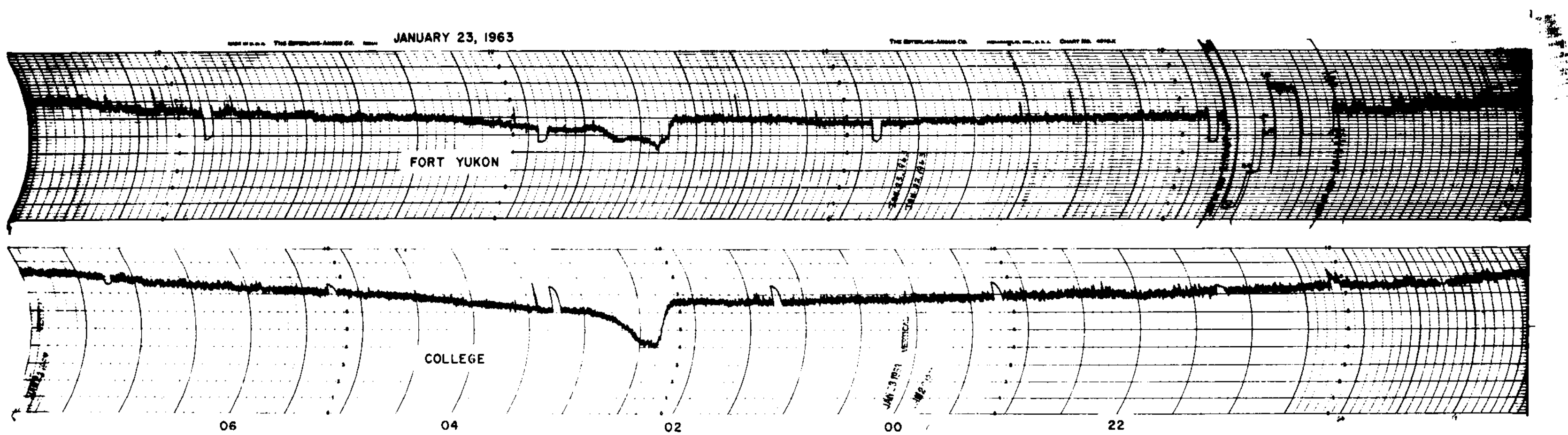

Fig. 22 Original riometer records for the breakup event of Jan. 23, 1963 showing the associated Type S events at Fort Yukon and College. Compare this figure with the all-sky photographs for this event presented in Fig. 23.

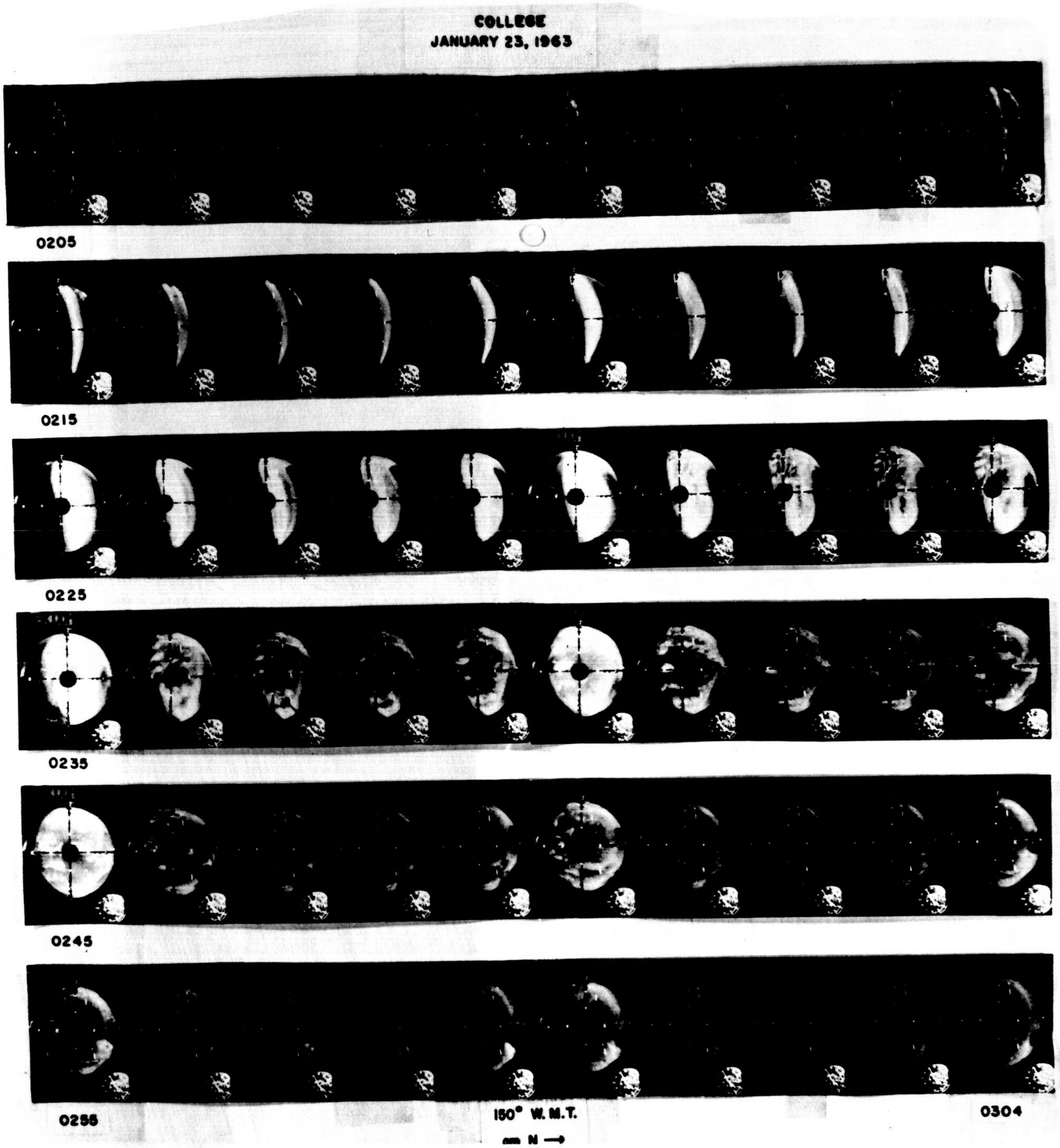

Fig. 23 All-sky photographs taken during the breakup event of Jan. 23, 1963. Note that the time of disappearance of the patches closely coincides with recovery of the absorption to quiet conditions. Compare this figure with Fig. 22.

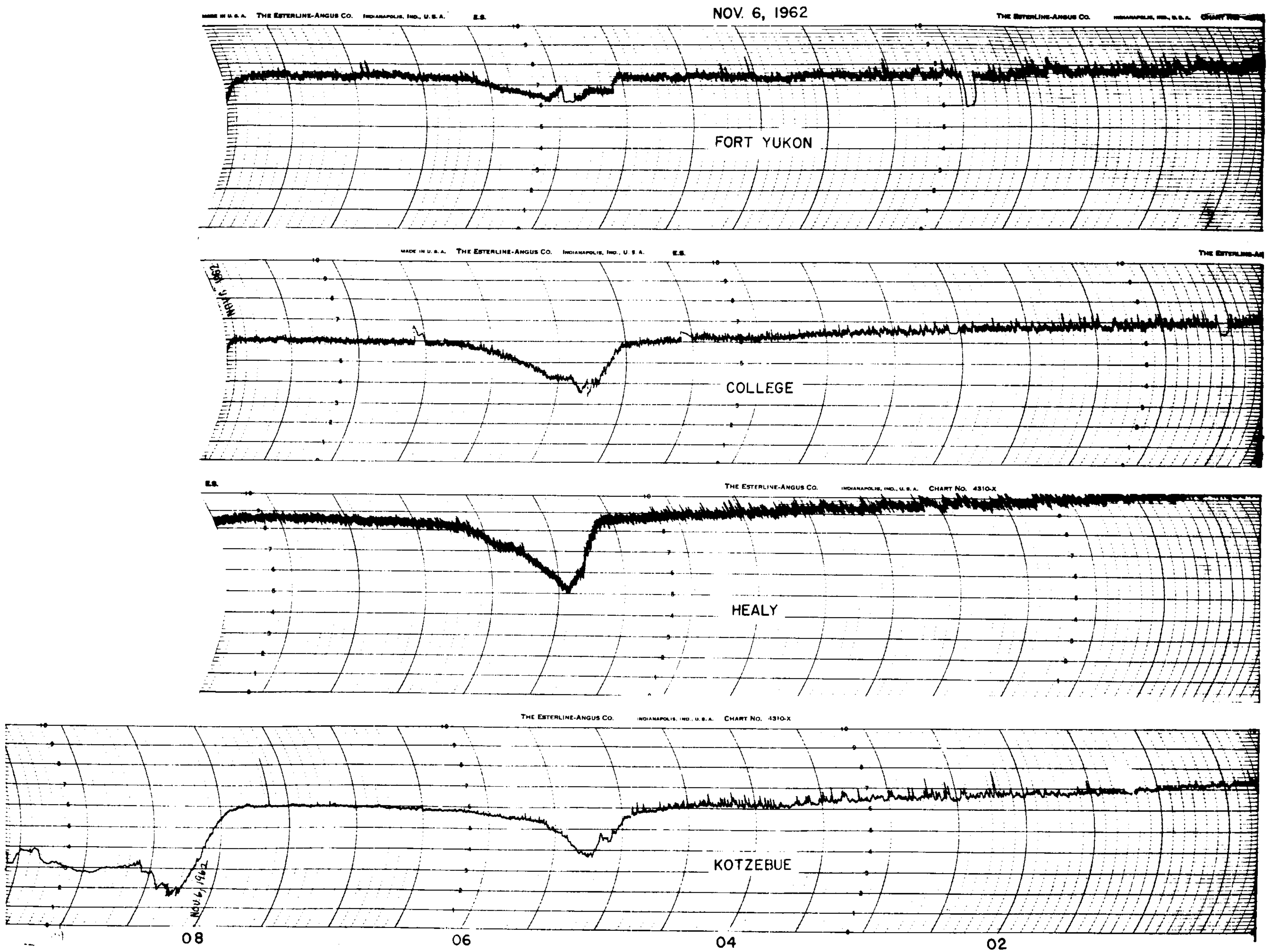

Fig. 24 **Original riometer records for the breakup event of Nov. 6, 1962 and the** accompanying Type S events at Fort Yukon, College, Healy, and Kotzebue showing the variation of absorption with geomagnetic latitude.

CHAPTER V

CONJUGATE STUDIES OF AURORAL ABSORPTION

5.1 Introduction

In a review of conjugate geophysical phenomena, Mather and Wescott (1963) have recommended that conjugate areas be defined more exactly. The study of cosmic noise absorption has proven useful in the investigation of conjugate areas. Both Hook (1962) and Leinbach and Basler (1963) have been able to correlate auroral and polar cap absorption events occurring in nearly conjugate areas. In particular, Leinbach and Basler have demonstrated a slightly higher degree of correlation between absorption at Macquarie Island, in the South Pacific, and at Kotzebue than at other Alaskan stations. However, almost the same degree of correlation existed between each Alaskan station and Macquarie Island and also between any pair of Alaskan stations. They were also able to show a close relation between both the magnitude and structure of absorption events.

Eriksen, et al. (1964) have made a similar investigation. Examining the daily and seasonal variation of conjugate absorption events, they found a daily maximum occurring near local geomagnetic midnight and a seasonal maximum in winter. They also noted a time lag of several minutes between the absorption maxima at the conjugate stations.

5.2 Discussion of Results

In this study, the data from Macquarie were analyzed independently of the data from the Alaskan stations, although in the same manner. Of the three types of absorption events (Types F, S or P) observed at Macquarie, 30 per cent occurred simultaneously with events at one or more of the Alaskan stations (principally Kotzebue or College). Note that simultaneity must be defined for each class of events; simultaneous Type F events occur within plus or minus two minutes of each other, while Type S events cannot be resolved within plus or minus 10 minutes. Table 3 lists the simultaneous events and the magnitude of these events at each station. There was greater correlation between the magnitude of the absorption occurring at Kotzebue and at Macquarie Island than between Macquarie Island and College. The correlation coefficients are also tabulated in Table 3. From this, one may conclude that the details of cosmic noise absorption observed in conjugate regions are related in magnitude when certain characteristic features are considered.

It would be useful to utilize a feature of high-latitude absorption in identifying and defining magnetically conjugate regions. Ideally, the occurrence of such a feature should be limited in space so that the conjugate region may be defined within as small an area as possible.

It should be noted that any widespread feature of constant magnitude over one hemisphere is intrinsically incapable of leading to a sharp definition of conjugate pairs.

Absorption bays, since they develop out of quiet conditions, might be useful for such an identification. However,

TABLE 3

DATE	150° W.M.T.	MQ	KOT	COL	FY	TYPE
Jan. 14, 1962	0534	2.6	2.8	3.1	ND	S
Jan. 29	0438	1.1	1.6	1.4	NE	S
Jan. 30	0430	1.2	1.1	1.6	1.4	S
Feb. 7	0432	3.3	3.4	2.4	NE	S
Feb. 16	0923	2.1	C	0.8	C	F
Feb. 18	0910	2.9	3.1	4.3	ND	S
Mar. 3	0520	0.7	0.8	1.3	ND	S
Mar. 5	0315	2.5	3.0	1.3	ND	F
Mar. 6	0217	0.8	C	C	2.7	F
Correlation Coefficient with Macquarie Island		1.0	0.98	0.59	-	

C = Complex absorption event, no identifiable features

ND = No data

NE = No identifiable event

the time of maximum absorption cannot be well defined for these events and there is some evidence that they may not be observed at certain latitudes (>67° gm).

On the other hand, the Type F (breakup) events can easily be identified in time and are observed, often simultaneously, over a large area. During simultaneous events, the absorption varies to a large degree from station-to-station and has been observed to show gross differences within a region of several hundred kilometers. The scatter plots of simultaneously <u>identifiable</u> events shown in Fig. 25 indicate that the highest degree of correlation existed between events occurring at College and Healy which are separated by only 120 kilometers (N-S). Attention may be drawn to a rapid deterioration of the correlation coefficient at a distance of about 200 km, to the north of College. The correlation coefficients between College and the other stations used in this study are given in Table 4. It is significant that the coefficient deteriorates only slowly in the east-west direction (Kotzebue is 700 km west of College). Perhaps this may be, in some way, related to the well known tendency of luminous arcs to lie preferentially in the E-W direction.

An example demonstrating the conjugacy of pulsating absorption events (lasting more than four cycles) was not observed in this study; however, the data sample was not adequate. Perhaps by utilizing both the magnitude and the period of such events, the region of conjugacy could better be defined than through the use of either Type F or Type S events.

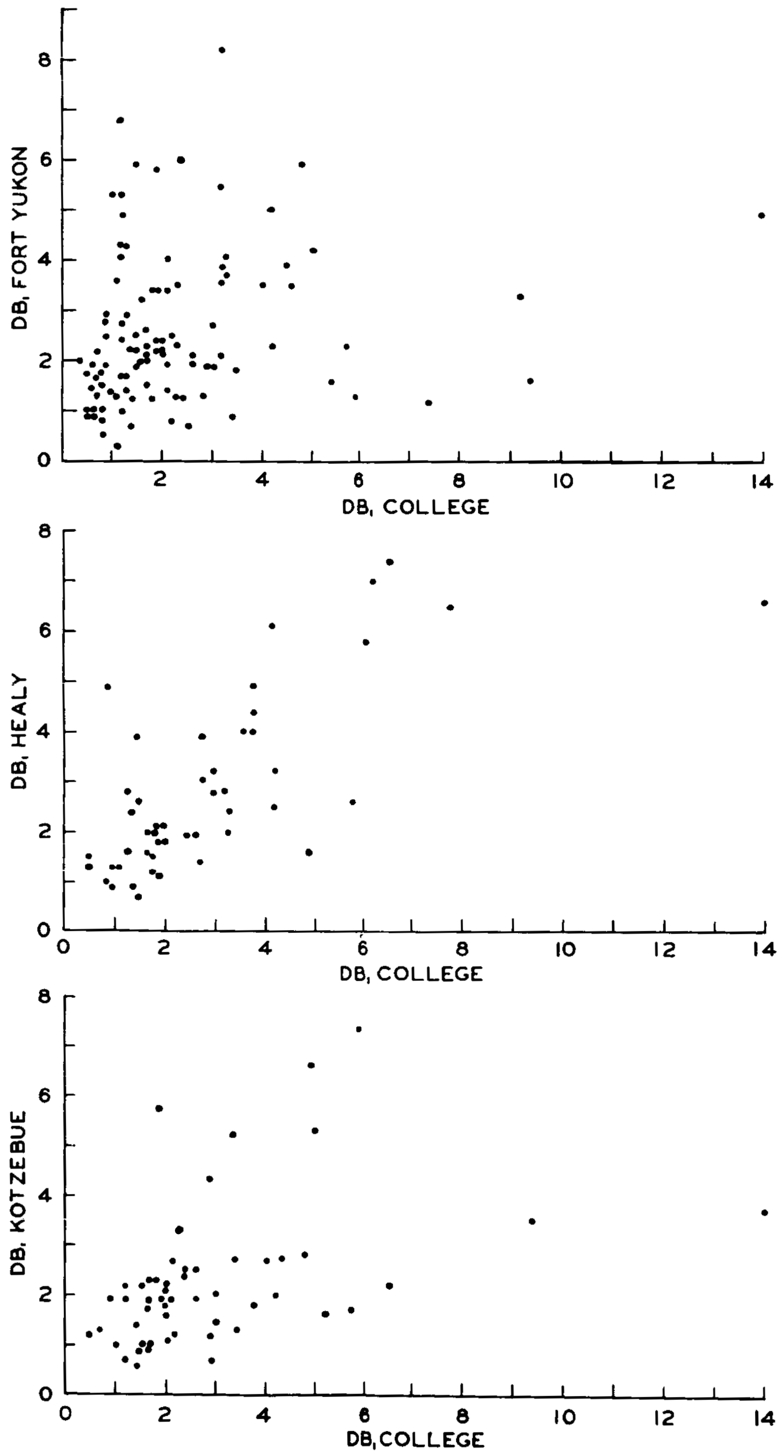

Fig. 25 Scatter plots of absorption magnitudes for events which were simultaneously identifiable between College and the other field sites. Note that the best correlation exists between College and Healy.

TABLE 4

	COL-FY	COL-KOT	COL-HEALY
Correlation Coefficient	0.22	0.41	0.58
Number of Events	89	35	41

Correlation coefficients for simultaneous Type F absorption events between College and Fort Yukon, College and Kotzebue, and College and Healy.

Type F events appear to be the most favorable class of events for use in studying conjugate absorption events and defining conjugate regions. This arises because: (a) Type F events can be resolved to $\pm$ 1 minute and (b) the absorbing region seems to be smaller than 100 kilometers.

The most common feature of the Macquarie records was the absorption bay or Type S event. Although only a limited amount of data has been used, this supports the earlier observation that Type S events are more frequent at geomagnetic latitudes less than 65°.

CHAPTER VI

MULTIPLE FREQUENCY ANALYSIS OF ABSORPTION EVENTS

6.1 Introduction

The analysis of single-frequency absorption data is not capable of deriving details of the ionization profile. In view of this difficulty, Parthasarathy, Lerfald, and Little (1963) have developed a technique for deriving electron-density profiles in the lower ionosphere utilizing cosmic noise absorption measurements at several frequencies. This technique has proven particularly valuable during disturbed ionospheric conditions. A detailed discussion of the technique is given by Parthasarathy et. al. and will be only briefly outlined here. For the instrumental details reference may be made to Parthasarathy and Lerfald (1964).

Radiowave absorption from any ionized stratum is a function of the wave frequency, the electron collision frequency, the electron gyrofrequency, and in the case of non-deviative absorption, it is also proportional to the electron density. Thus, for a narrow beam, zenithal directed antenna

$$A(f) = \int_0^\infty K(f, \nu_m, s, \phi) . N(h)\, dh \tag{1}$$

where the absorption as measured by the antenna is A, the K function is absorption per unit path (when the electron density is unity), and N is the electron density at height h. The specific absorption K is a function of the electron collision frequency ν_m (appropriate to the electrons with the most probable velocity), the wave frequency, f, the angle of propagation, ϕ, with respect to the magnetic field, and the electron gyrofrequency, s. The form of this function as used here is due to Sen and Wyller (1960), which takes into account the dependence of the collision frequency of each electron on its energy. For a convenient tabulation of the K function, see Chorbajian, Sugiura, and Parthasarathy (1962).

Any given N(h) function may be tested through the integral relationship (1) to see whether it satisfies the observed data at the observing frequencies. The larger the range of simultaneous radio-frequency data that are available, the more confidence one can place in the detailed validity of the derived electron density profile.

During auroral absorption events, Lerfald, Little, and Parthasarathy (1964) found that the observed absorption values often satisfied a simple power law of the form

$$A(f_e) = C \cdot f_e^{-n} \qquad (2)$$

where C is a constant, and $A(f_e)$ is the absorption in decibels at a given effective frequency f_e. The value of the exponent n and hence the derived ionization profile was also found by them to vary from event-to-event. The results of this technique will be used in the following sections for events which satisfied the condition of reasonably uniform ionization over the 60 degree beamwidth of the antenna.

6.2 Multiple frequency analysis of selected Type F events

Several events for which the absorbing region was known to be spread over a region of several hundred kilometers (i.e. observation of the event at several stations) were analyzed using multiple frequency data for the period 1961-62. These data were gathered at College over the same period during which the single frequency data were examined. The frequencies used in the multiple frequency study were 5^-, 5^+, 10^-, 10^+, 20^-, 20^+, 30, and 50 Mc/s where the plus and minus signs denote the extraordinary and ordinary waves respectively.

The exponent n in expression (2) was determined for each event under consideration. The value of the exponent varied from 1.1 to 1.8 and the average value was determined to be approximately 1.4. In Fig. 26 the shape of the electron-density versus height profile is given for $n = 1.45$. The data used in obtaining this profile were nighttime winter values. Depending upon the actual magnitude of absorption in any of the frequencies, this profile may be multiplied at every point by an appropriate factor to obtain the actual magnitude of absorption.

6.3 Multiple frequency analysis of Type S events

Sample electron-density profiles are shown in Fig. 27 and correspond to the Type S events of Fig. 8. Such profiles, which extend down to very low altitudes, seem compatible with ionization due to electrons and the associated X-ray Bremsstrahlung as proposed by Chapman and Little (1957) and Aikin and Maier (1963). A model electron-density profile was not uniquely established for either the Type S or Type F

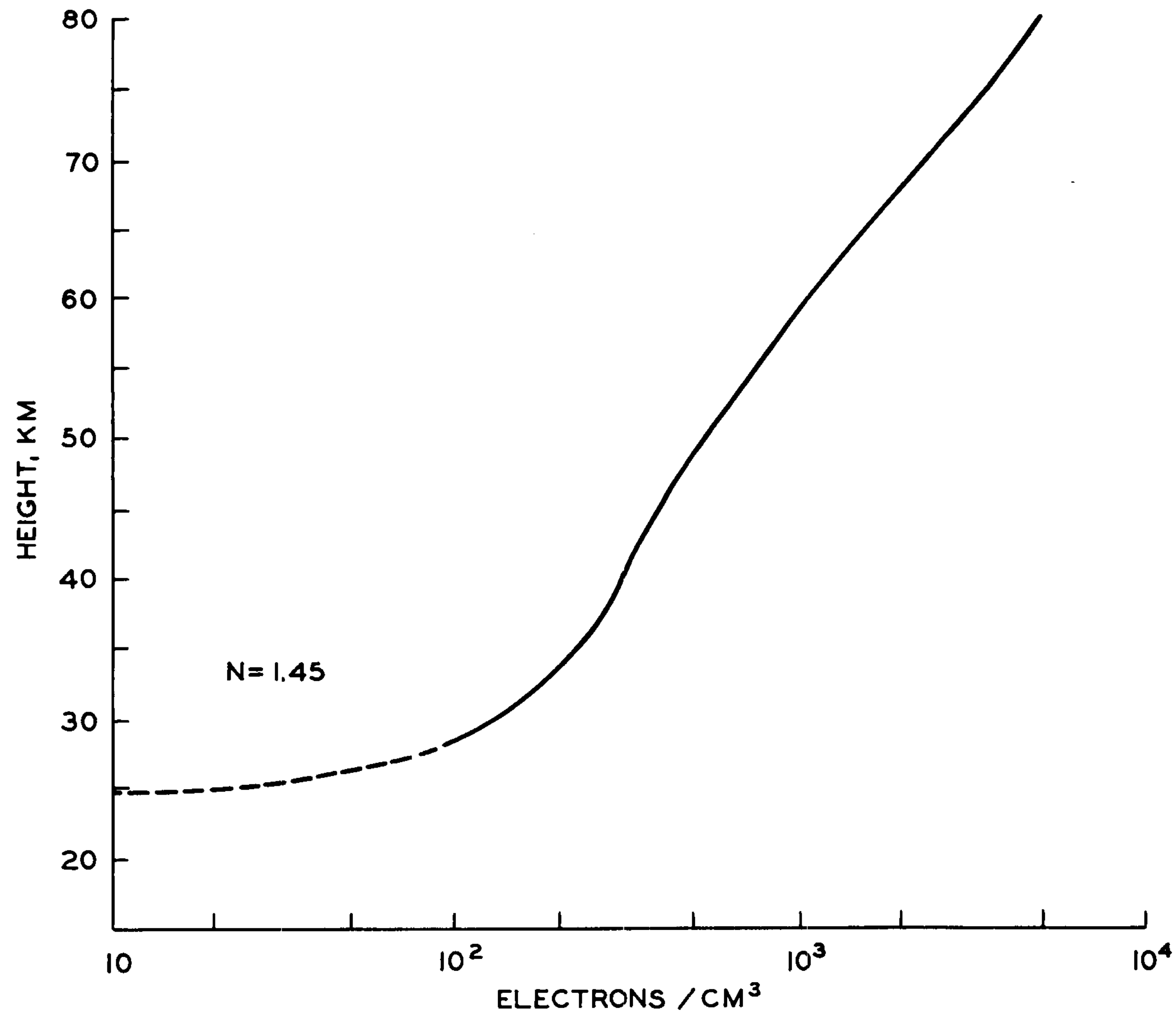

Fig. 26 Electron-density versus height profile computed by assuming n = 1.45. For this profile the vertically integrated absorption for the 10 Mc/s extraordinary wave totals 10 decibels.

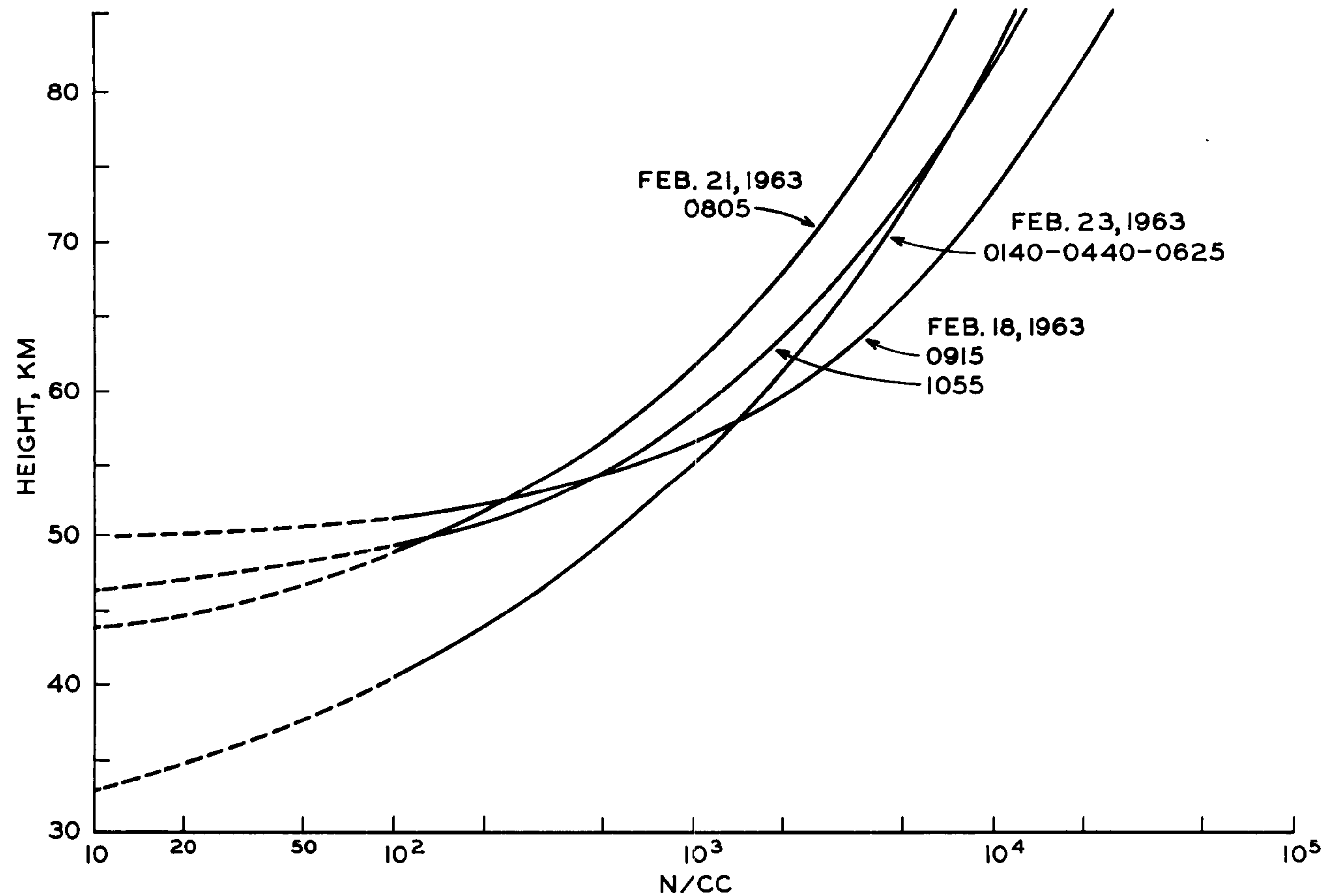

Fig. 27 Electron density profiles derived by using the radiowave absorption data from Fig. 8 and appropriate parameters (after Parthasarathy and Berkey, 1964). Note that the year should be 1962 not 1963.

events; in fact, at the current stage of understanding of the several aspects of the phenomena, a considerable degree of optimism would be required to advocate any particular model. However, it may be pointed out that in many cases considerable ionization existed down to the 50 km level; and also, no systematic differences in shape were noticeable between the profiles obtained during the daytime and those obtained in nighttime. If such a systematic difference had existed, it was presumably concealed by the variety of profiles in each group. Obviously then, the statistical studies of day-night ratios such as have been done by several workers in the past, have to be interpreted with greater caution.

6.4 Discussion

In using these profiles for deriving or verifying the primary electron flux and the energy spectrum, one has to know the rate coefficients of recombination, attachment, etc., as a function of height. The effective recombination coefficient, $\alpha_{eff}(h)$ may be derived by using the basic laboratory data in conjunction with the atmospheric parameters. Alternative approaches would be to derive the coefficients by two independent methods: (a) by means of a set of polar cap absorption event N(h) profiles, and the corresponding satellite measured proton flux data; and, (b) by means of the N(h) profiles obtained during a special sub-category of rapidly recovering events of the Type F class. These two independent techniques have given reasonably self-consistent values of α_{eff} which appear to be somewhat higher than those available in the literature [Parthasarathy and Berkey (to be published)].

A direct inference concerning the Type F and S events would, therefore, be that the properties of the luminous features of the associated auroral displays discussed in Chapter 4 are to be interpreted as concomitant effects, rather than causative factors of the radio wave absorption.

CHAPTER VII

DISCUSSION AND CONCLUSIONS

7.1 Introduction

The purpose of this chapter is to consolidate and to elaborate on the results obtained in the earlier chapters. At this point perhaps the purpose of this study should be reviewed: (a) to obtain the spatial and temporal characteristics of the distinct absorption events into which high-latitude cosmic noise absorption records may be classified, and; (b) to relate these distinct events to other associated geophysical phenomena, principally visual aurora and magnetic disturbance. As noted before, the distinct categories studied here have been individually recognized and investigated by various workers, but their spatial and temporal aspects have not been thoroughly analyzed before.

7.2 Spatial and temporal characteristics

Each of the three types of absorption events investigated in this study was recognizable in the riometer data from the four Alaskan field stations, which are situated at varying geomagnetic latitudes, and also in the data from Macquarie Island, in the South Pacific. The frequency of occurrence of each event was found to vary with geomagnetic latitude. Type S events were most frequent at the latitudes of Healy and Kotzebue, while Type F events occurred most often at College and Fort Yukon. Type P events were noted most often at Healy. No marked seasonal variation was found for any type of event; however, a tendency toward a fall maximum was evident for Type F events. At all stations Type F events occurred most frequently around local midnight, while Type S events were noted in the pre-dawn hours. The time of occurrence of Type P events varied with latitude, becoming later as lower latitudes were approached.

In the graphs displaying the frequency of occurrence of the magnitude (in decibels) of the different types of events it was observed that a particular magnitude was favored and that this particular magnitude varied with latitude. Therefore, it is felt that some physical significance should be attached to this result; it would seem quite premature to propose any convincing, unique mechanism at this stage. Two possibilities may be mentioned: (a) some type of shock-excited mechanism (for Type F events) and: (b) a buildup of certain instabilities which may favor a certain particle flux. Both of these mechanisms can occur in the magnetosphere.

7.3 Relation to magnetic disturbance

A good correlation was found between the occurrence of Type F absorption events and the <u>occurrence</u> of negative bay disturbances of the magnetic H-component. However, there was no relation between the <u>magnitude</u> of the sudden increase of absorption and the magnitude of the corresponding change in the H-component (see Fig. 18). This result implies that the energy spectrum of the incoming particles responsible for the increased ionization varies from event-to-event. For example, an abundance of low energy particles in the spectrum may produce greater ionization at 100 km than at lower heights, resulting in a greater magnetic effect due to an increased current flow.

Type S events were found to correlate with positive bay disturbances before midnight and negative bay disturbances after midnight. A few events were not accompanied by magnetic disturbance, however such events were not considered in detail.

Type P events were usually found to be accompanied by magnetic pulsations, although not always in phase with one another. It should be pointed out that the occurrence of regular pulsations is very frequent in both the magnetometer and earth current records, while absorption pulsations of definite periodic structure are extremely rare. Since the magnetic pulsations have been attributed to hydromagnetic oscillations, it would seem that an extra factor must be invoked to explain the (less frequent) pulsations in the radiowave absorption records.

7.4 Relation to visual aurora

In this study Type F events were found to be associated with the breakup phase of auroral arcs near the midnight meridian. This association has been discussed in detail by Ansari (1963) and Gustafsson (1962).

It was found that Type S events are related to the breakup phase of quiet auroral arcs near the dawn meridian. During such events the absorption appeared to be related to the presence of moving auroral forms, rather than the degree of brightness of such a form. In the course of the breakup event, the absorption began to increase when the arc began to expand equatorward and had recovered when the eastward drifting patches were no longer visible. This implies that the absorption magnitude may be related to the rate of expansion of auroral forms. It should be noted that a rapid poleward expansion accompanies the breakup phase near the midnight meridian.

Due to a lack of all-sky camera data during periods of pulsating absorption, it could not be determined from this study if Type P events were correlated with any particular aspect of the aurora.

7.5 Relation to conjugate point identification

An observational approach, intrinsically capable of defining a pair of conjugate 'points' within the narrowest possible area, should first seek a natural phenomenon known, at any instant, to be confined to a limited area in one of the hemispheres. Examples are, isolated quiet arcs and auroral jet currents. Here it has been shown that the Type F event is readily distinguishable during periods of absorption and is localized in magnitude. From Table 4 it can be seen that the correlation of magnitude for simultaneous Type F events was not very high, even between College and Healy, (for College-Healy 0.57 and for College-Fort Yukon, 0.26) which are separated by only 120 km. Thus it appears that Type F absorption events are capable of defining a conjugate region to at least 100 km in latitude.

Type S events, although easily distinguishable, cannot be resolved with accuracy to within 5 minutes due to the rather broad maximum of absorption. For a number of simultaneous events (predominantly Type S), observed both at Macquarie, Kotzebue, and College it was found that the correlation was very high between Macquarie and Kotzebue, although only a limited number of events were considered. Thus Type S events may also be useful in defining conjugate regions, especially at latitudes where Type F events are not commonly observed; however, they are not capable of defining the conjugate region as exactly as are Type F events.

7.6 Multiple frequency analysis

The study of Type F events utilizing multiple frequency cosmic noise data has led to the conclusion that the energy spectra of incoming particles varies from event-to-event, in agreement with the conclusion obtained as a result of the study of magnetometer records. The change in the energy spectrum is implied through the variance of the exponent n in the expression (2) of Chapter 6. This exponent was found to range from 1.1 to 1.9, a change of at least 50 per cent. The ionization profiles which extend down to 40 km during these events may be contrasted with the ionization responsible for the luminosity of the aurora ($\approx$ 120 km) as well as for the magnetic effects ($\approx$ 120 km).

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